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INFORMATION SERVICES PLATFORMS AT GEOSYNCHRONOUS EARTH ORBIT

A Requirements Analysis

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY



MCDONNELL DOUGLAS CORPORATION



**INFORMATION SERVICES PLATFORMS
AT GEOSYNCHRONOUS EARTH ORBIT**

A Requirements Analysis

FEBRUARY 1978

MDC G7308

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-WEST

5301 Bolsa Avenue, Huntington Beach, CA 92647

PREFACE

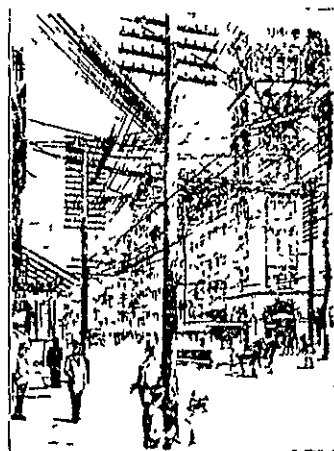
This document summarizes the results of an analysis prepared by the McDonnell Douglas Astronautics Company for the Langley Research Center under Task Number 28 of NASA Contract NAS1-12436. The purpose of this task has been to investigate the potential user requirements for Information Services Platforms at geosynchronous orbits and to provide a rationale for identifying the corollary system requirements and supporting research and technology needs.

Questions regarding this activity or the material contained in this document should be directed to:

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TELEPHONE WIRES IN NEW YORK IN 1890

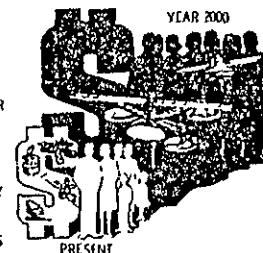
POLE LINES IN NEW YORK AT A TIME WHEN THERE WERE ABOUT 8 000 TELEPHONES ON MANHATTAN ISLAND. WITHOUT THE RESEARCH THAT PRODUCED UNDERGROUND CABLES, AND THEN LATER MICRO-WAVE RELAYS, THE GROWTH OF THE TELEPHONE SYSTEM WOULD HAVE STOPPED.

SINCE THE BELL TELEPHONE SYSTEM
A W PAGE 1940

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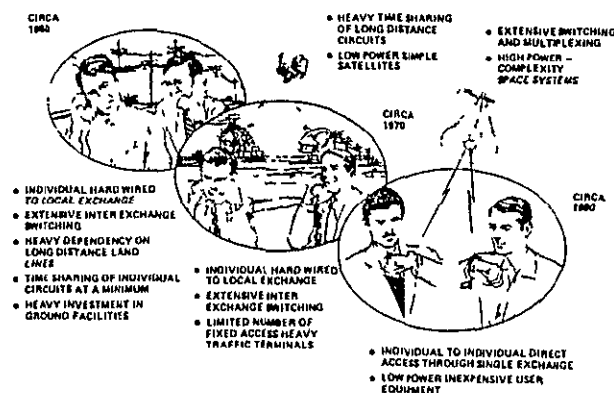
COMMENTS ON WORLD MARKET FOR INFORMATION SERVICES

- INCREASE IN POPULATION BY 2000 WILL GENERATE NEW MARKETS IN COMMUNICATIONS RELATED EQUIPMENT AND SERVICES OF \$50 TO \$100 BILLION PER YEAR
- ADDITIONAL INVESTMENT IN PLANT AND EQUIPMENT EQUIVALENT TO \$100 TO \$200 BILLION BY 2000
- DEVELOPING NATIONS ADVANCE SOCIOECONOMICALLY THROUGH DOMESTIC PRODUCTION, USE OF LOW-COST EARTH STATIONS AND LEASING CIRCUITS FROM HIGH TECHNOLOGY TELECOMMUNICATIONS SATELLITES

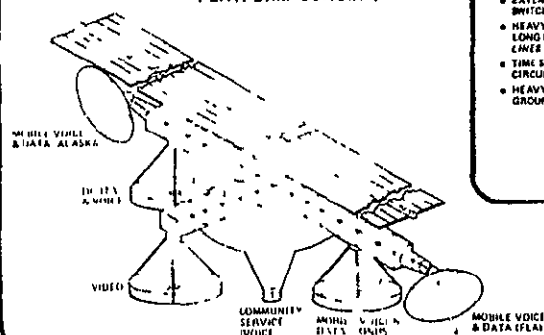


- U.S. AND DEVELOPED NATIONS BENEFIT BY PROVIDING NEW SPACE TECHNOLOGY AND SYSTEMS TO DEVELOPING NATIONS

COMPLEXITY INVERSION FOR FUTURE PERSONAL COMMUNICATIONS



PLATFORM CONCEPT



GEOSYNCHRONOUS INFORMATION SERVICE PLATFORMS

- EXPAND SERVICES ON A GLOBAL BASIS
- LOWER EARTH STATION COSTS BY COMPLEXITY INVERSION
- DEVELOP TECHNOLOGY TO BUILD AND OPERATE INFORMATION SERVICE PLATFORMS
- BENEFITS TO THE UNITED STATES
 - KEEP AHEAD OF FOREIGN COMPETITION
 - EXPORT PRODUCTS AND SERVICES FAVORABLE TO BALANCE OF TRADE
- KEY ADVANCE TECHNOLOGY AREAS
 - MICROWAVE COMPONENTS
 - LARGE PRECISION ANTENNAS
 - HIGH POWER CAPABILITY
 - SPACE CONSTRUCTION MATERIALS AND METHODS
 - MANIPULATED OPERATIONS AT GEOSYNCHRONOUS ORBIT



INFORMATION SERVICES PLATFORMS

A REQUIREMENTS ANALYSIS

35606

- OBJECTIVES
- HUMAN FACTORS IN COMMUNICATIONS
- POPULATION STATISTICS, ECONOMIC GROWTH, AND COMMUNICATION NEEDS
- COMMUNICATION EXPENDITURES
- CURRENT CAPABILITIES
- DEMAND GAP
- REGULATORY CONSTRAINTS AND PHYSICAL LIMITATIONS
- CHARACTERISTICS OF FUTURE SYSTEMS
- KEY TECHNOLOGY DRIVERS
- CONCLUSIONS

OBJECTIVES

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This document reports on a brief analysis of the domestic and international market potential for geo-synchronous Information Services Platforms between the present time and the year 2000. It was believed that through examination of both functions and growth requirements, a limited number of system models could be hypothesized to anticipate the various classes of future needs. These models would provide a basis for suggesting the likely system development requirements and technological growth steps necessary to meet those needs. These identified system requirements in turn would provide a basis for identifying promising areas for support when plans for research and development projects were undertaken and funds allocated.

Topics considered on the following pages include population and economic factors, growth requirements, current capabilities, the demand gap, regulatory constraints and physical limitations, characteristics of future systems, and key technology considerations.

INFORMATION SERVICES PLATFORM AT GEOSYNCHRONOUS EARTH ORBIT

36508

A REQUIREMENTS ANALYSIS

OBJECTIVES -

- TO EXAMINE KEY COMMUNICATION/INFORMATION RELAY SERVICE FUNCTIONS
- TO IDENTIFY POTENTIAL GROWTH/DEMAND FOR INFORMATION SERVICES PLATFORMS AT GEOSYNCHRONOUS EARTH ORBIT THROUGH THE YEAR 2000
- TO IDENTIFY SYSTEM REQUIREMENTS AND TECHNOLOGY DRIVERS FOR FUTURE GEOSYNCHRONOUS INFORMATION SERVICES PLATFORMS

In the last several years, studies, symposia, and technical articles have reported on potential information services and communications systems, suggesting numerous applications that could serve the projected needs of mankind. The facing chart summarizes typical communications functions as suggested by seven recent, representative sources.

Communications satellites designed for multiple voice circuits, data exchange satellites involving transfers of wideband, high-data-rate blocks of information, and direct broadcast satellite systems and communication linkages to mobile terminals are indicative of the emerging capabilities foreseen by these sources. Basically, these systems can fulfill point-to-point, point-to-points, and points-to-point communications requirements. They will serve the needs of private, civic, industrial, governmental, international, and scientific users.

Telecommunications and their importance in the modern world are well recognized. Therefore, in order to provide topical continuity in the discussions that follow, examples pertinent to personal telecommunications frequently will be used to illustrate the issues, requirements, and problems anticipated in the development of Information Services Platforms. The conclusions and recommendations regarding system requirements and technological needs, however, will be applicable to all the space systems necessary to service the multitude of potential applications summarized on the facing chart.

Such functional classification systems foster completeness of coverage and reduce the potential for overlooking possible applications. Irrespective, however, of the classification system used to describe the applications, the driving force behind communications growth is people — their numbers, their needs, and their desires to enhance their socioeconomic growth.

COMMUNICATIONS DEFINED

REPRESENTATIVE SOURCES	POTENTIAL FUNCTIONS					
FUTURE NATIONAL NEEDS AEROSPACE – NASW2727	PERSONAL	CIVIC	INDUSTRIAL	GOVERNMENT	INTERNATIONAL	SCIENTIFIC
OUTLOOK FOR SPACE NASA SP-386	DOMESTIC TELECOMMUNICATIONS		INTERCONTINENTAL POINT TO POINT		PERSONAL MOBILE SERVICES	DATA COLLECTION
SURVEY OF SPACE APPLIC NASA SP-142	POINT-TO-POINT SYSTEMS		BROADCAST SATELLITES	RELAY SATELLITES	INFORMATION COLLECTION	DATA RELAY SATELLITES
PUBLIC SERVICE WORKSHOP GSFC – MAR 1977	INFORMATION AND MESSAGES	EDUCATION (INCL MEDICAL)	ENVIRONMENT COMMUNICATIONS	PUBLIC BROADCASTING	RELIGIOUS APPLICATIONS	GOVERNMENT
PRELUDE TO 2001 CHAPANIS – NASA NGR 21-001-073	WRITING		READING		TELEPHONING	TALKING FACE-TO-FACE
SERVICE NEEDS MARSTEN – MAY 1977	POINT-TO POINT			POINT-TO-POINTS		POINTS TO-POINT
TECHNOL REQ FOR COMMUN SAT IN 1980'S LMSC – OCT 1973 NASA CR 114680	DOMESTIC TV	TELEPHONE AND HIGH SPEED DATA NETWORKS	AERO/MARINE	TRACKING AND DATA RELAY	EARTH RESOURCES DATA COLLECTION	RF MONITORING AND TEST

HUMAN FACTORS IN COMMUNICATIONS

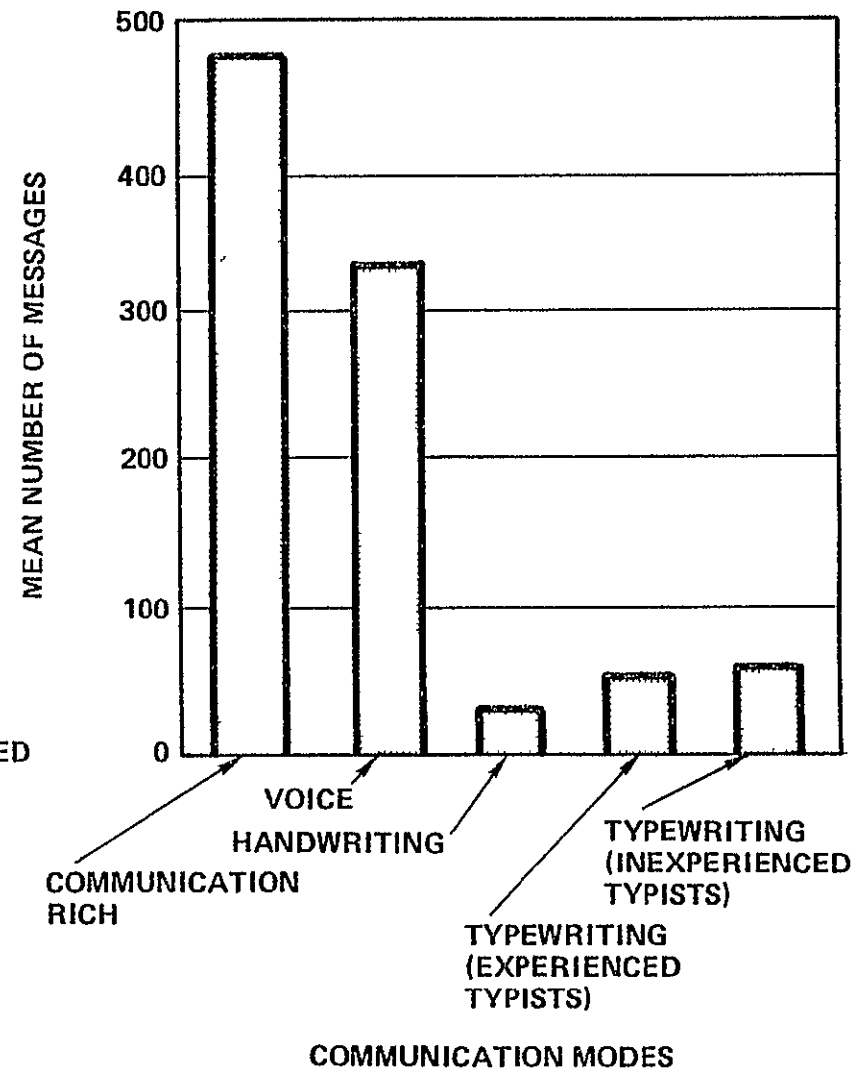
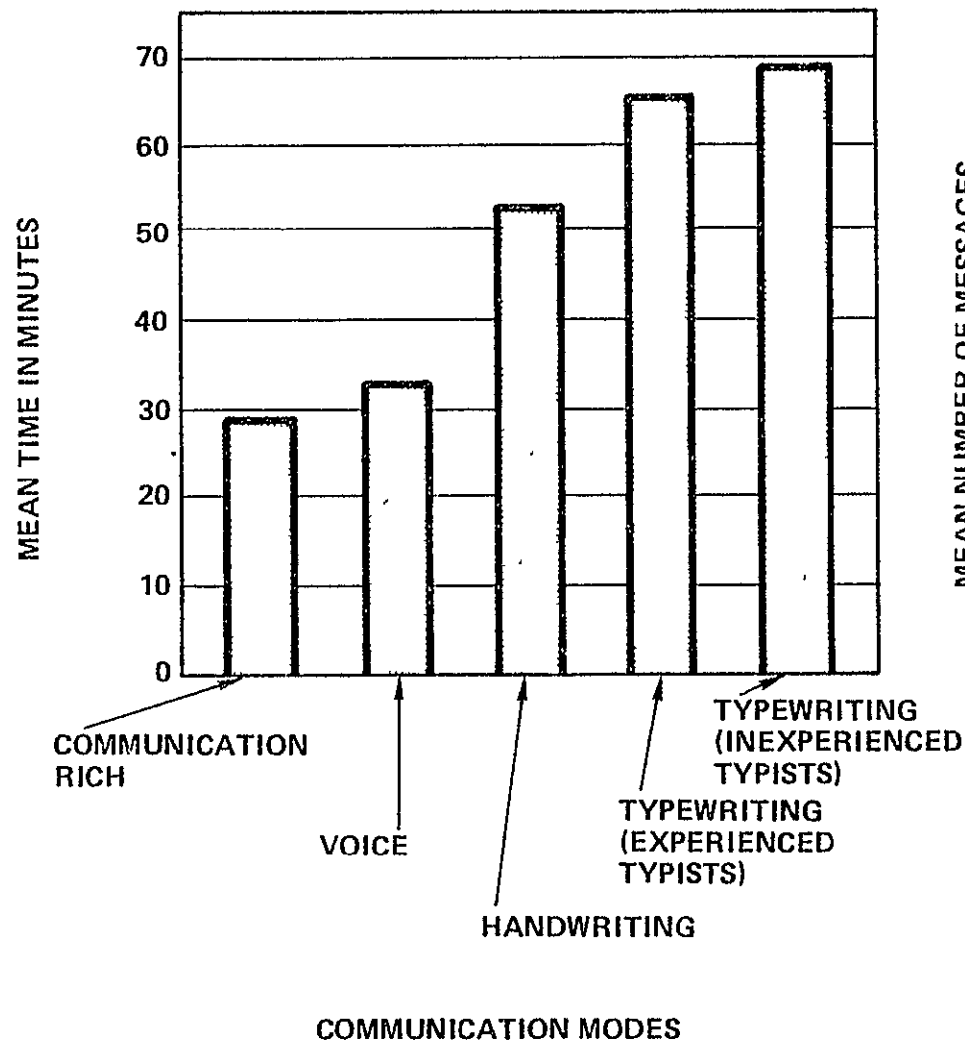
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In research conducted at Johns Hopkins University to determine what happens when people communicate naturally, three different modes of telecommunications and one direct communications mode were examined while subjects attempted to solve complex problems. In the typewriting mode, subjects communicated through special slaved typewriters. Whatever one subject wrote on one machine appeared simultaneously on his partner's machine. In the handwriting mode, subjects wrote messages back and forth. In the voice mode, subjects were able to talk freely but were not able to face each other directly. In the communication-rich mode, subjects were in direct view of one another and were able to converse naturally using voice, gestures, and handwriting. Both voice and communication-rich modes gave the best performance. Problems were solved through voice communications two and one-half times faster than with the typewriting mode. Surprisingly, however, the difference between the communication-rich and the voice modes was relatively small. Gestures, facial expressions, and handwriting appeared to offer only slightly improved performance over pure oral communication. If this finding were supported by further studies, the practical value of videophones for general use, for example, might not be great enough to warrant the expanded bandwidth that would be required in an already crowded spectrum. Priority in future system design might better be given to increasing voice channel coverage rather than expanding video channels, as required for videophone or Picturephone¹.

1. Registered trademark of the American Telephone and Telegraph Company.

TIMES AND NUMBER OF MESSAGES REQUIRED TO SOLVE COMPLEX PROBLEMS

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SOURCE: PRELUDE TO 2001: EXPLORATION IN HUMAN COMMUNICATION, A. CHAPANIS, JOHN HOPKINS UNIV, APRIL 1971

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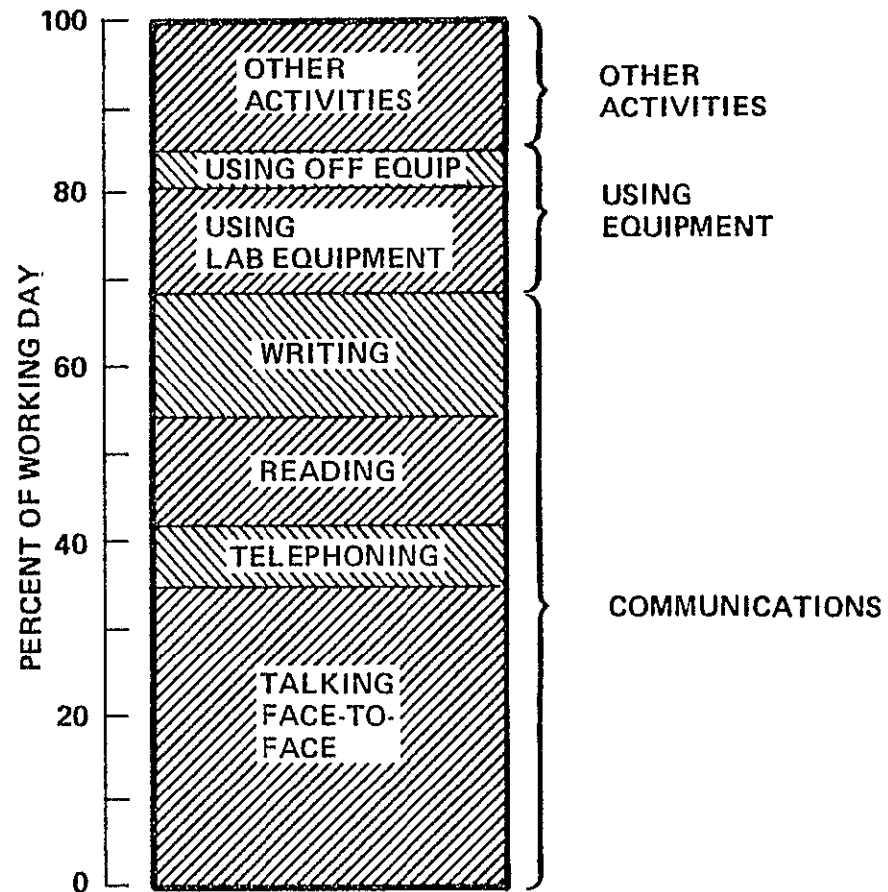
Society can be classified in terms of preindustrial, industrial, and postindustrial development. Most of the world today is essentially preindustrial and is engaged in extractive work: mining, fishing, timber, and agriculture. For industrial societies, the majority of the labor force engages primarily in industry and manufacturing. The US is typical of the postindustrial type of society in that the majority of the labor force is engaged essentially in services, that is, trade, finance, education, research, administration, and government.

Accordingly, communication is, and will continue to be, an important segment of our everyday life. In a research program at the Bell Telephone Laboratories, E. T. Klemmer observed activity patterns of more than 3,000 persons during their working day. On the average, the people in Klemmer's study were found to have spent over two-thirds of their time in some form of communication. This finding is believed typical of modern industrial and postindustrial societies and it is not expected that communication-related activities will diminish in the foreseeable future. This means that communication will continue to occupy a significant portion of our working time in the coming decades regardless of whether we work at remote stations, at home, or in large industrial-technical complexes.

As more of the countries of the world progress from preindustrial into industrial and postindustrial society, their needs for such fundamentals as equality, liberty, health, education, income, and power will grow irrepressibly and irreversibly. The facilities for communications must expand to meet this growing demand.

PROPORTION OF WORKING DAY SPENT IN VARIOUS ACTIVITIES (1)

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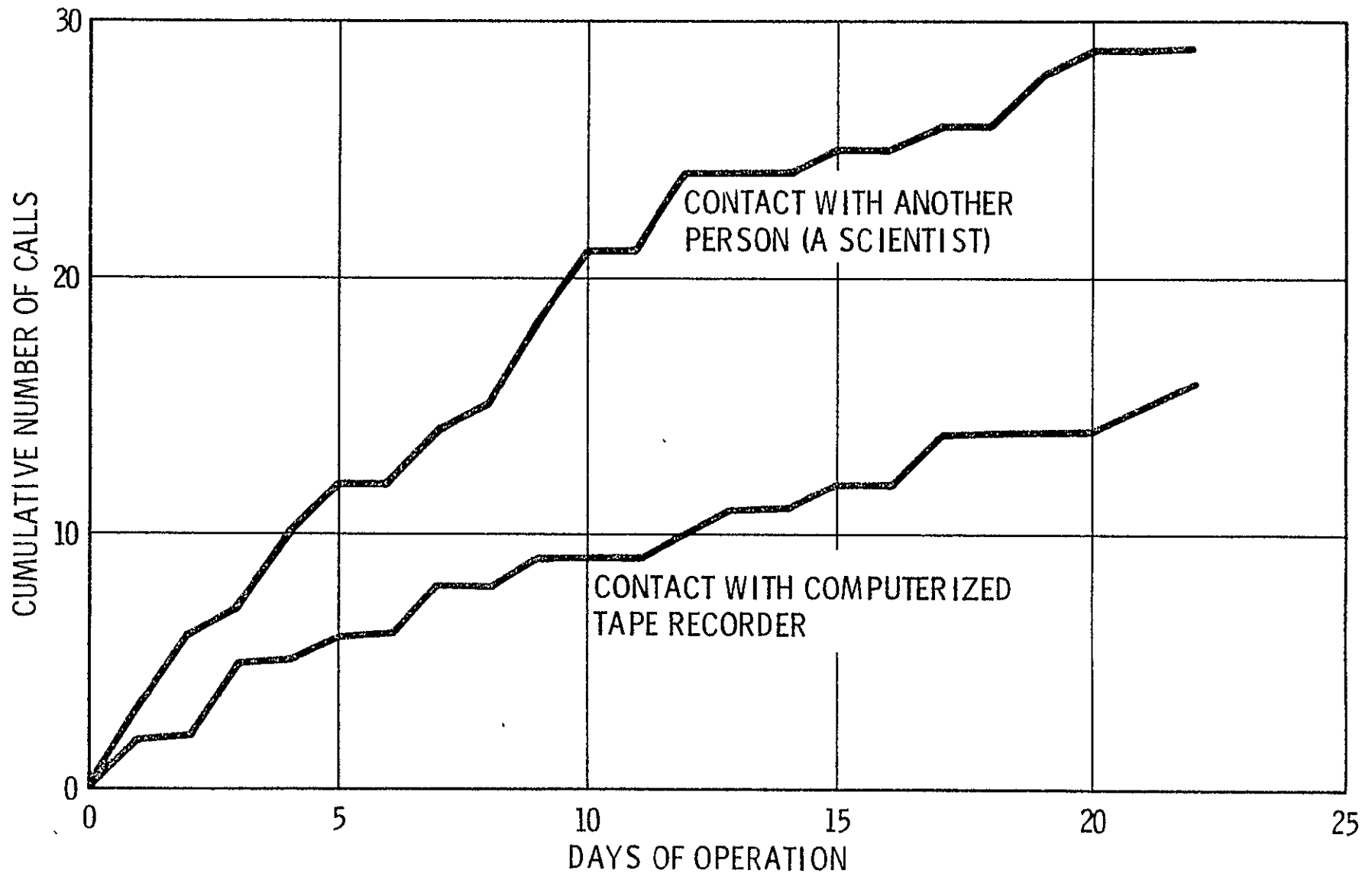
(1) CLERKS, SECRETARIES, TECHNICIANS, PROFESSIONAL PEOPLE AND SUPERVISORY PERSONNEL –
(AFTER CHAPANIS, APRIL 1971)

Considerable evidence supports the thesis that communication systems should respond with human or human-like interaction. People prefer to communicate with people or people-like systems, when the information to be communicated is complex or unstructured. In a study conducted by Kinkade and associates in cooperation with the Federation of American Societies for Experimental Biology, scientists with questions to be answered were invited to transmit their requests by telephone to a central office. Answers were returned at a later time. Requests were received either by a biologically trained scientist or by a tape recorder. Requests were tape recorded in all instances. Users were free to choose either the human or the machine receptionist. From the data gathered, it seems clear that, given a choice, users more often preferred to interact with a human than with an impersonal machine.

In brief, from a human factors standpoint it would appear that (1) personal communications will be a growing requirement in the coming decades, with a significant portion of our working day being spent in some form of communications and (2) people will continue to talk to people. The real value of specific system concepts to satisfy user requirements, however, must be further assessed, and some selectivity may be required in matching system concepts and applications. As noted earlier, while videophones can be demonstrated to provide increased performance over simple voice communication in specific applications, the degree of improvement may not be enough to warrant the bandwidth required for the more general application of this concept.

CUMULATIVE NUMBER OF REQUESTS TELEPHONED TO BIOLOGICAL INFORMATION CLEARINGHOUSE

35269A



SOURCE: PRELUDE TO 2001: EXPLORATION IN HUMAN COMMUNICATION, A. CHAPANIS JOHN HOPKINS UNIV, APRIL 1971

POPULATION STATISTICS, ECONOMIC
GROWTH, AND COMMUNICATION NEEDS

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Inasmuch as it is people who communicate with people, it is reasonable to base the current and projected future needs for communications-related services on population statistics. The facing chart tabulates some basic demographic and economic indicators. Estimates are included for the current calendar year, with trends projected to the year 2000. The source of these data is the Population Reference Bureau, which gathers, interprets, and publishes information on the facts and implications of national and world population trends. Headquartered in Washington, DC, the Bureau is a private non-profit educational organization that consults with other groups and operates an international program and information service.

The Bureau publishes annually the World Population Data Sheet, summarizing demographic statistics by region and listing all geopolitical entities with a population larger than 200,000. Data available for 1977 from the sheet include current population estimates, population projection to 2000, and per capita gross national product.

The total world population, as estimated by the Bureau, will increase about 2 billion from a mid-1977 total of 4,083 million, to a year 2000 total of 6,182 million. This growth in world population would result in a real increase in gross national product (GNP) in proportion to the relative population increase. Assuming no regional growth in GNP per capita (which represents maintenance of the status quo), net estimated increase in population multiplied by the average GNP for each region equates to the increase in GNP as shown in the fifth column on the chart. The sum total for the seven regions would amount to \$1,702 billion over the next 23 years. On the other hand, the worldwide average GNP per capita amounts to \$1,530 per person. If this average were achieved by every region, considering the 2,099 million increase in population by the year 2000, some \$3,211 billion would be added to the GNP. This would result, for example, if the developing regions such as Asia and Africa experienced a real increase in per capita GNP along with their expected increase in population. The most likely increase in GNP can be assumed to fall somewhere between the \$1,702 and \$3,211 billion figures.

As pioneered by Leontief,^{1,2} and supported by many economists, an "input-output" technique has been developed to analyze and to measure the interrelationships between various producing and consuming factors within a national economy. Using the input-output structure of the US economy as a model³, it has been determined that about 3% of the GNP is made up of industries providing communications-related goods and services.

Limited studies of other nations' economies have shown them to be similar to the US input-output structure, which means that the above-stated fraction of communications-related GNP to the total GNP would probably hold true elsewhere.

Using the 3% figure, by the year 2000, on a world-wide basis, between a \$50-billion and \$100-billion per annum increase can be expected in communications-related goods and services. In absolute terms, the figures represent a major market opportunity for new communications goods and services.

-
1. The Structure of American Economy, 1919-1929: W. W. Leontief, Harvard University Press, 1941.
 2. Input-Output Economics: W. W. Leontief, Oxford University Press, 1966.
 3. Revised Input-Output Tables for the United States: 1967, Bureau of Economic Analysis Staff, Page 29, June 1977.

WORLD POPULATION AND GNP 1977 - 2000

GEOGRAPHICAL REGION	POPULATION - MILLIONS			GROSS NATIONAL PRODUCT		
	1977	2000	INCREASE	PER CAPITA (\$)	INCREASE (\$)	X3% ⁽¹⁾ (\$)
AFRICA	423	811	388 (19%)	400	155B	5B
ASIA	2325	3584	1259 (60%)	530	667B	20B
NORTH AMERICA	240	294	54 (>2%)	7020	379B	11B
LATIN AMERICA	336	608	272 (13%)	1030	63B	2B
EUROPE	478	539	61 (3%)	4090	249B	7B
USSR	259	314	55 (>2%)	2620	144B	4B
OCEANIA	22	32	10 (<1%)	4490	45B	1B
TOTAL WORLD	4083	6182	2099 (100%)	1530	1702B	51B (2)
					3211B	96B (3)

B - BILLIONS \$ - USA DOLLARS

NOTES: (1) BASED ON BEA INPUT/OUTPUT TABLES FOR COMMUNICATIONS-ORIENTED INDUSTRIES
 (2) COLUMN TOTAL
 (3) ROW CALCULATION

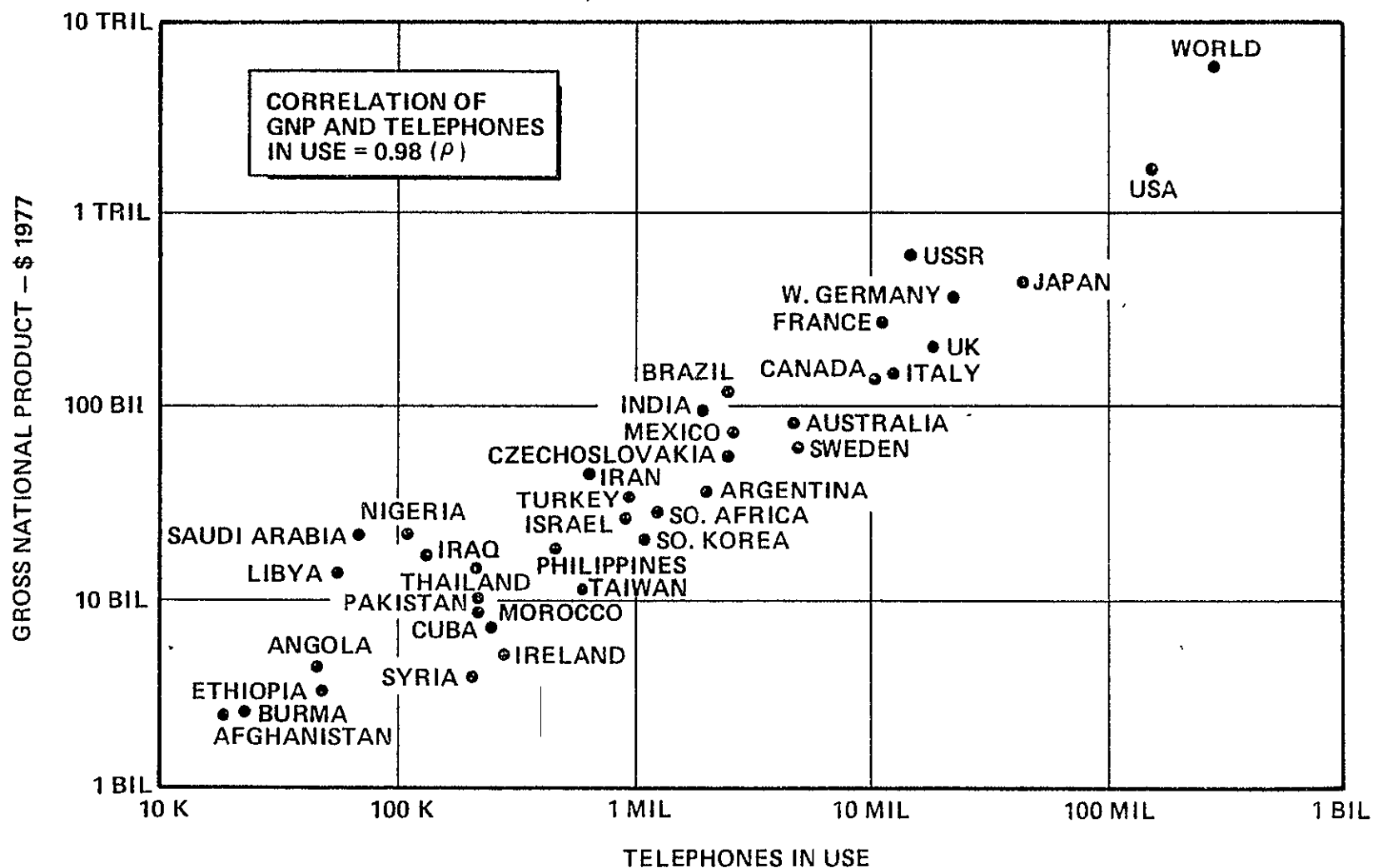
SOURCE: 1977 WORLD POPULATION DATA SHEET, POPULATION REFERENCE BUREAU, WASHINGTON, D.C.

For 36 nations representing each of the seven regions of the world, statistics for GNP and number of telephones in use are plotted on the facing chart. Also shown is the world total of \$6.2 trillion GNP and 350 million telephones in use as of 1977. The postindustrial US, representing a GNP of about \$1.5 trillion and using about 142 million telephones, dominates all other regions and nations.

Statistically, there is a high degree of correlation (0.98) between the two parameters shown on the chart. Therefore, it is possible to derive an expression relating the number of telephones to GNP. Since GNP is also a function of population, an increase in demand for telephones also can be expected to be experienced for an increase in real population.

For the total world, 90 additional telephones are required for each GNP increment of \$1 million. The world GNP can be projected to increase somewhere between \$1.7 and \$3.2 trillion over the next 23 years. On the basis of 90 telephones per \$1 million, this increase in GNP would equate to a range of 153 million to 288 million telephones.

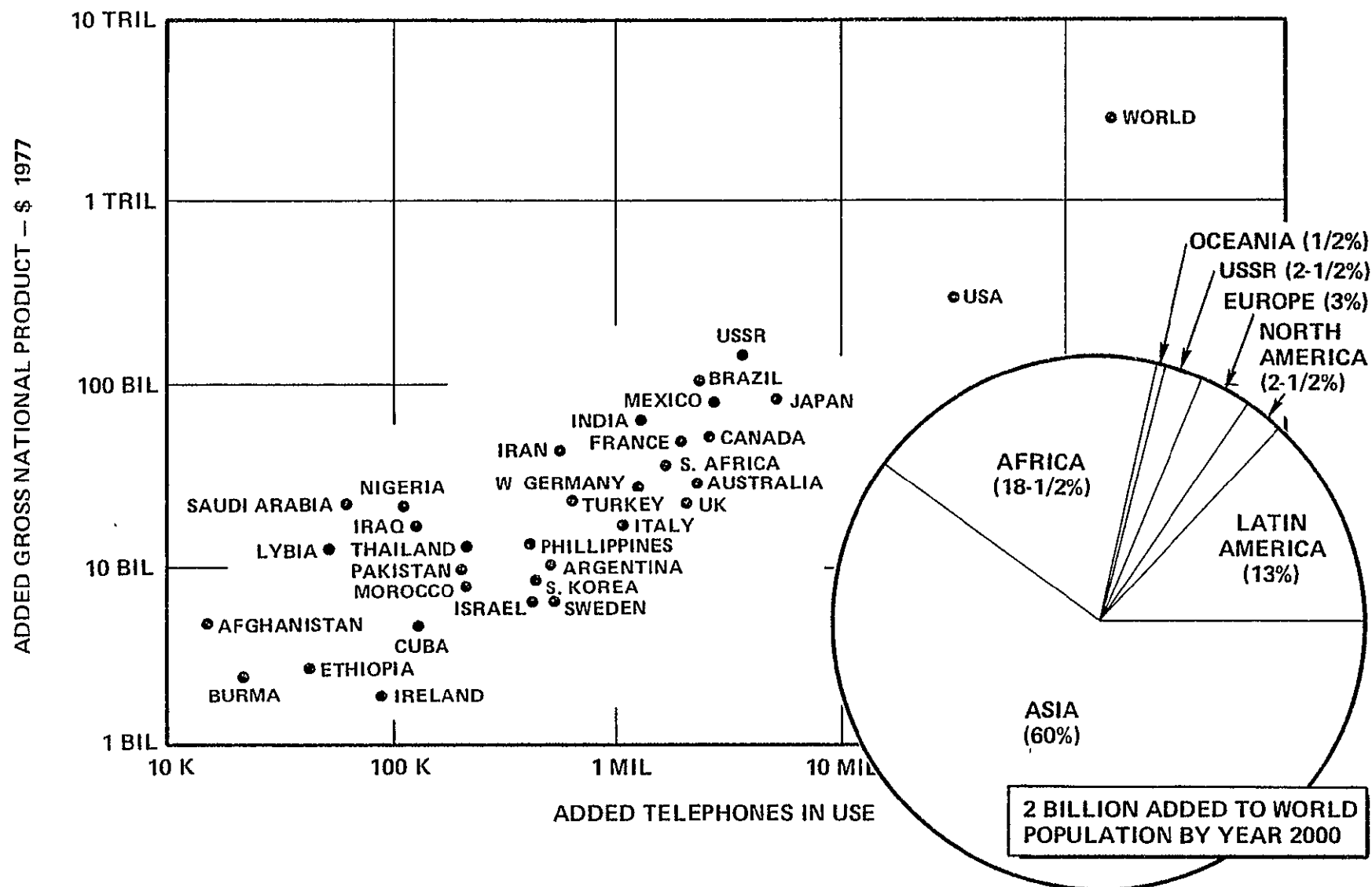
TELEPHONES IN USE- 1977



The facing chart presents the additional capacity required by the year 2000 for the 36 nations shown, using the same statistical averages of GNP per capita and telephones per capita described earlier. As shown, 20 of the 36 nations would require the addition of 500,000 or more telephones.

The circular plot depicts geographically the relative distribution of the expected population increase over the next 23 years. About 80% of the increase will occur between longitudes of 0° and 120° east, or about 13-1/3 million increase for each degree of longitude within this range. The communications satellite implications of this trend will be discussed in more detail subsequently.

ADDITIONAL TELEPHONES IN USE BY THE YEAR 2000 AND GNP GROWTH



A recent NASA-sponsored study conducted by the Aerospace Corporation¹ described a wide range of future potential information services, including many "new initiatives," both civilian and military. Fourteen of the civilian initiatives, chosen from the total on the basis of (1) telecommunications applications and (2) the fact that they require advanced satellite antenna systems, are listed on the facing chart. The fourteen applications as shown on the chart can be broadly classified as to the type of telecommunications demand, i. e., (1) high-data-rate point-to-point communications, (2) multiple-access points-to-point, and (3) broadcasting point-to-points.

Only one of the fourteen initiatives was classified in the first category, namely 3D/holographic telecommunications. As described in the study, this class of service most probably would be limited to very important government-, private-business-, or public-service-related conferences held at the very highest levels, leaving considerable capacity during periods of non-use to be made available for massive data transfer functions.

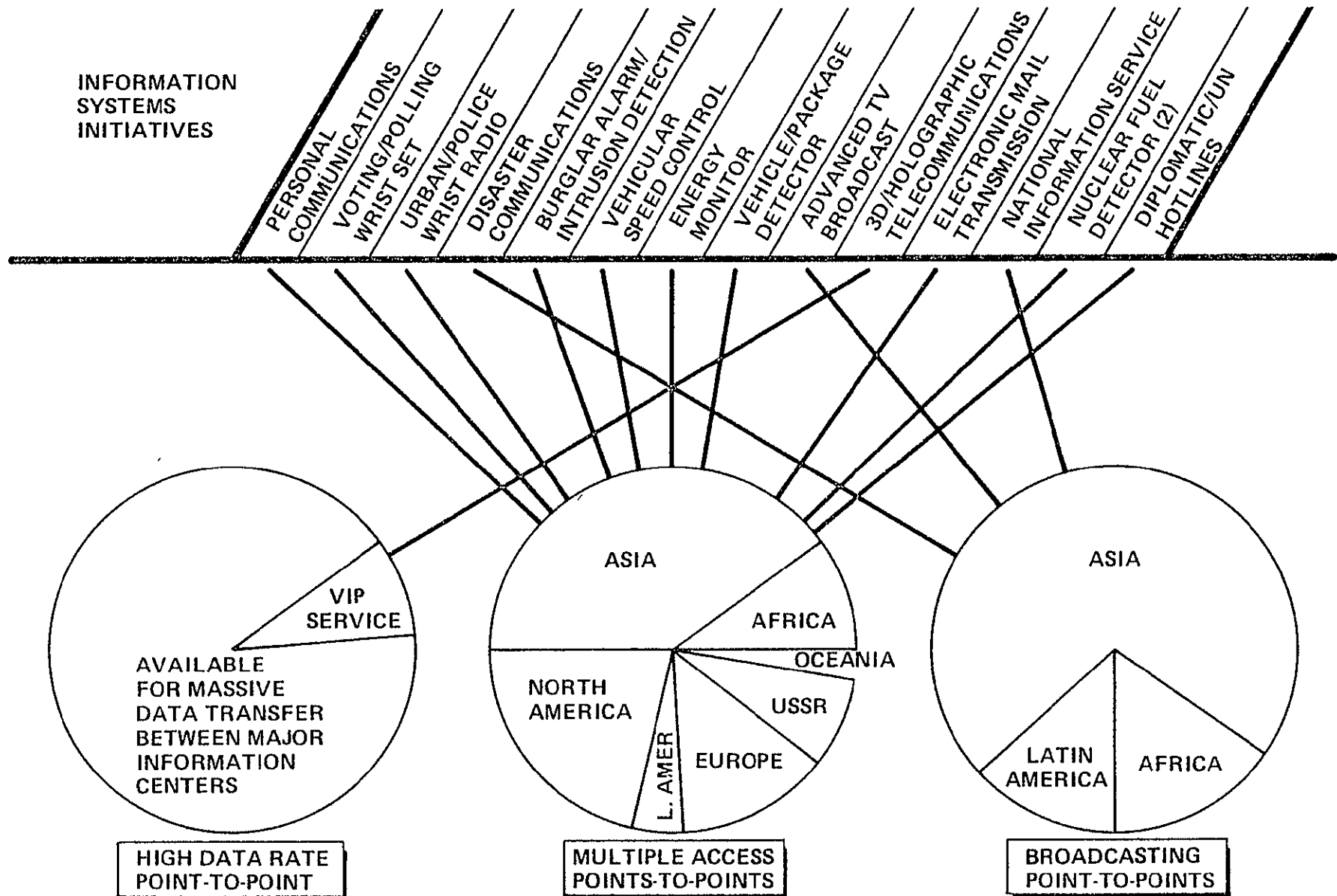
Ten applications were classified in the second category and are shown distributed by geographic region and relative demand. The allocation by region was based upon projected growth and level of GNP by the year 2000. On this basis, Asia represents the single largest future market.

Three applications were believed to be of greatest use to the developing preindustrial regions of the world. In these instances, the developed countries already possess considerable mass media communications (radio and TV) capabilities and these applications would therefore not represent major new market opportunities as such in the more developed regions.

1. Advanced Space Systems Concepts and Their Orbital Support Needs, Aerospace Corporation, ATR-76 (7365)-1, NASA Contract NASW-2727, 1977.

EACH OF THREE CLASSES OF TELECOMMUNICATIONS DEMAND SUPPORT DIFFERENT CONSTITUENCIES

35791



(DISTRIBUTED BY MARKET POTENTIAL) (DISTRIBUTED IN EMERGING REGIONS)

SOURCE: ADVANCED SPACE SYSTEMS CONCEPTS 1980-2000, AEROSPACE CORP NASW 2727, 1976

Another example of the value and potential of communications satellites may be found in the Satellite Instructional Television Experiment (SITE), an ambitious undertaking that beamed lessons, information, and entertainment from space into isolated villages in India. The project lasted from June 1975 through August 1976, during which time some 2-1/2 million people living in areas especially chosen for their backwardness were drawn into what could be called a university for the uneducated.

The ATS-6 Satellite was loaned for SITE by NASA to the Indian Space Research Organization. Programs were transmitted to 2,400 villages, where they were received on small and inexpensive Indian-made antennas that fed community television sets. Four regional languages were used as well as standard Hindi. The cost to India of the project was about 6 million pounds.

SITE was a success technically, in that all the experimental aims were met. The social implications of the project are being widely studied by the developing countries in order to determine if television can be used as a means to encourage and advance national development. SITE marks the beginning of an era when countries with power to launch communications satellites or with the economic and political means to command and control satellites can broadcast directly into sets in their own or in other countries. SITE made India the first nation to introduce mass television to rural areas before all of its major metropolitan areas had it.

SATELLITE INSTRUCTIONAL TELEVISION EXPERIMENT.

(SITE)

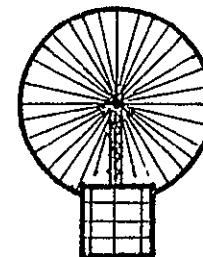
35784

- SATELLITE LOANED BY NASA TO INDIAN SPACE RESEARCH ORGANIZATION FROM JUN 1975 TO AUG 1976
- PROGRAMS TRANSMITTED TO 2,400 VILLAGES AT A COST OF £6 MILLION TO INDIA. 2.5 MILLION PEOPLE RECIPIENTS OF LESSONS, INFORMATION, AND ENTERTAINMENT
- SITE RESULTS BEING WIDELY STUDIED BY DEVELOPING COUNTRIES AS A MEDIUM FOR FORCING NATIONAL DEVELOPMENT. AS AN EXPERIMENT AIMS WERE MET AND RESULTS WERE TECHNICALLY SUCCESSFUL
- INDIA FIRST COUNTRY TO INTRODUCE MASS TELEVISION TO RURAL AREAS BEFORE ALL METROPOLITAN AREAS HAVE IT

SOURCE: THE ECONOMIST (BRITISH),
AUGUST 2, 1975



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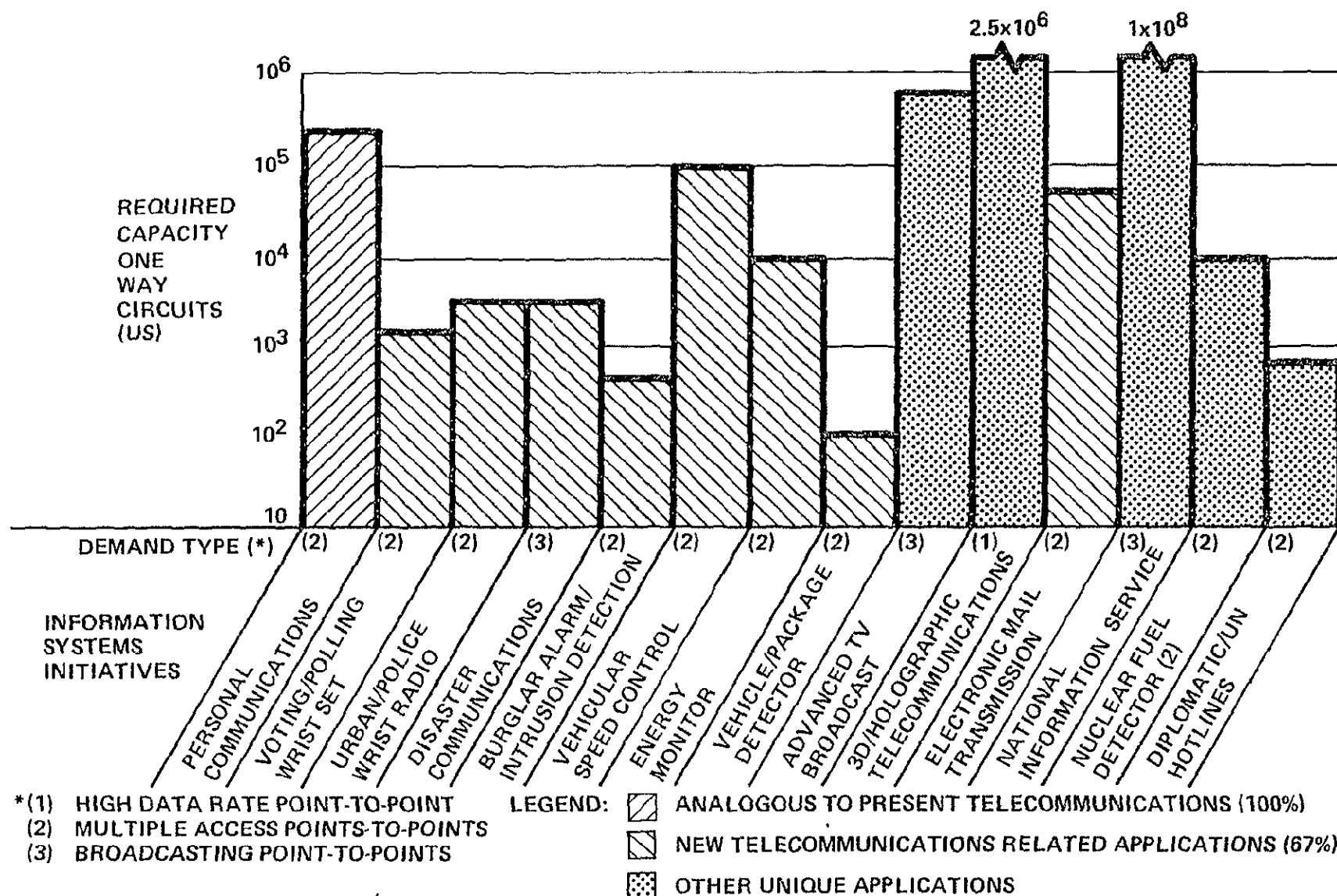
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For each of the 14 information systems initiatives shown on the facing chart, an estimate of required capacity is presented. The capacity is stated in terms of the parameter "one-way voice circuits" based upon the description contained in the referenced Aerospace documentation and an analysis of the potential demand using the US as a demographic model. Factors considered in arriving at the estimates included the following:

1. Total number of potential users of the service
2. Number of local areas that could be serviced
3. Frequency and duration of use
4. Amount and bandwidth of information to be transferred
5. Population projections for US

Because the personal communications initiative offers user services similar to those of present telecommunications systems, the relative capacity of this service was established as a baseline. Eight initiatives, closely related to personal communications but existing presently only on a very limited basis, represent new telecommunications-related initiatives for the future. Their total capacity is projected to equate to about 67% of the telephone baseline. This factor becomes a useful index in projecting new and emerging demand for advanced applications extrapolated to worldwide markets. The remaining five initiatives, such as advanced TV broadcasting and 3D/holographic teleconferencing, are unique applications and, as such, require further analysis before meaningful projections of actual capacity requirements can be made. In fact, 3D/holographic teleconferencing may require an order-of-magnitude more capacity than the personal communications initiative.

DISTRIBUTION OF REQUIRED CAPACITY



SOURCE: ADVANCED SPACE SYSTEMS CONCEPTS 1980-2000, AEROSPACE CORP NASW 2727, 1976

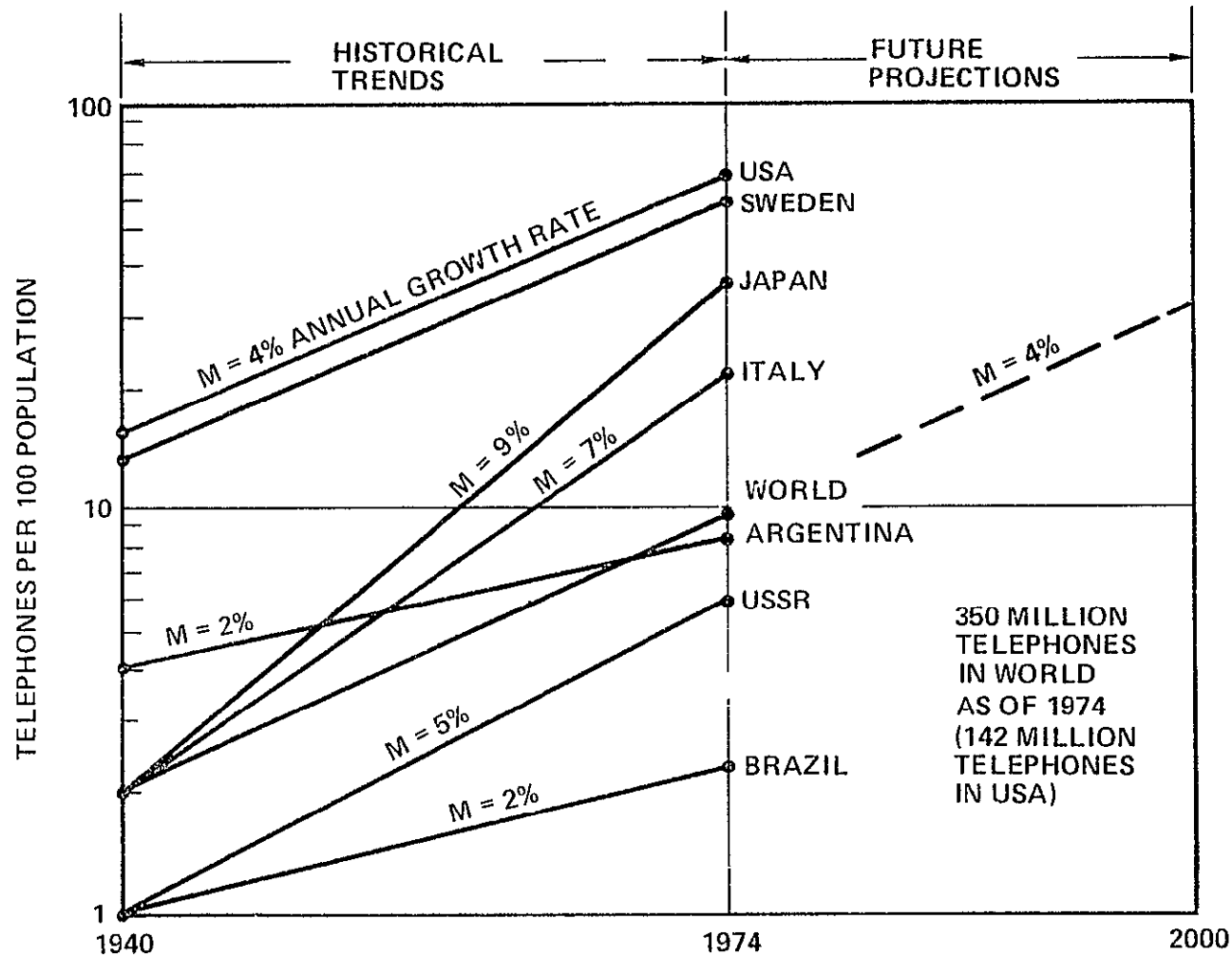
The facing chart plots historical trends in the growth of telephone service. The trends for seven countries and the world in total were based upon data documented by the Bell Telephone System in the year 1940 and by statistics provided by the Statistical Abstract of the United States (which also includes selected statistics of other nations) published by the US Department of Commerce.

The historical worldwide annual growth in telephone service between the years 1940 and 1974 was about 4%, the same growth rate as was observed for the US and Sweden. Japan experienced a 9% growth during the same period, which reflects the rapid industrial and economic growth of that country. Brazil, a very large and sparsely populated preindustrial nation, was characterized by the relatively low rate of growth of only 2% during the period.

A reasonable world future growth rate of 4% was projected to continue to the year 2000. An increase in telephones from 8.6 to 32 per capita will be realized if this 4% growth trend continues.

As pointed out in an earlier chart, telephones and GNP correlate closely. Therefore, an index number based upon "telephones per 100 capita" would be representative of real economic growth normalized against population increase.

TELEPHONE SERVICE GROWTH IN THE WORLD



SOURCES OF DATA: THE BELL TELEPHONE SYSTEM, PAGE, 1940; STAT ABSTR OF US, 1976

As discussed earlier, population increase projected over the next 23 years will result in a significant real GNP growth. For example, it was cited that for each GNP incremental increase of \$1 million, some 90 additional telephones would be needed throughout the world. These assumptions did not take into account, however, a general rise in the standard of living with its attendant increase in the number of telephones per capita. However, the previous chart clearly shows that in recent history, on a worldwide basis, telephones per capita have increased at an annual rate of 4%.

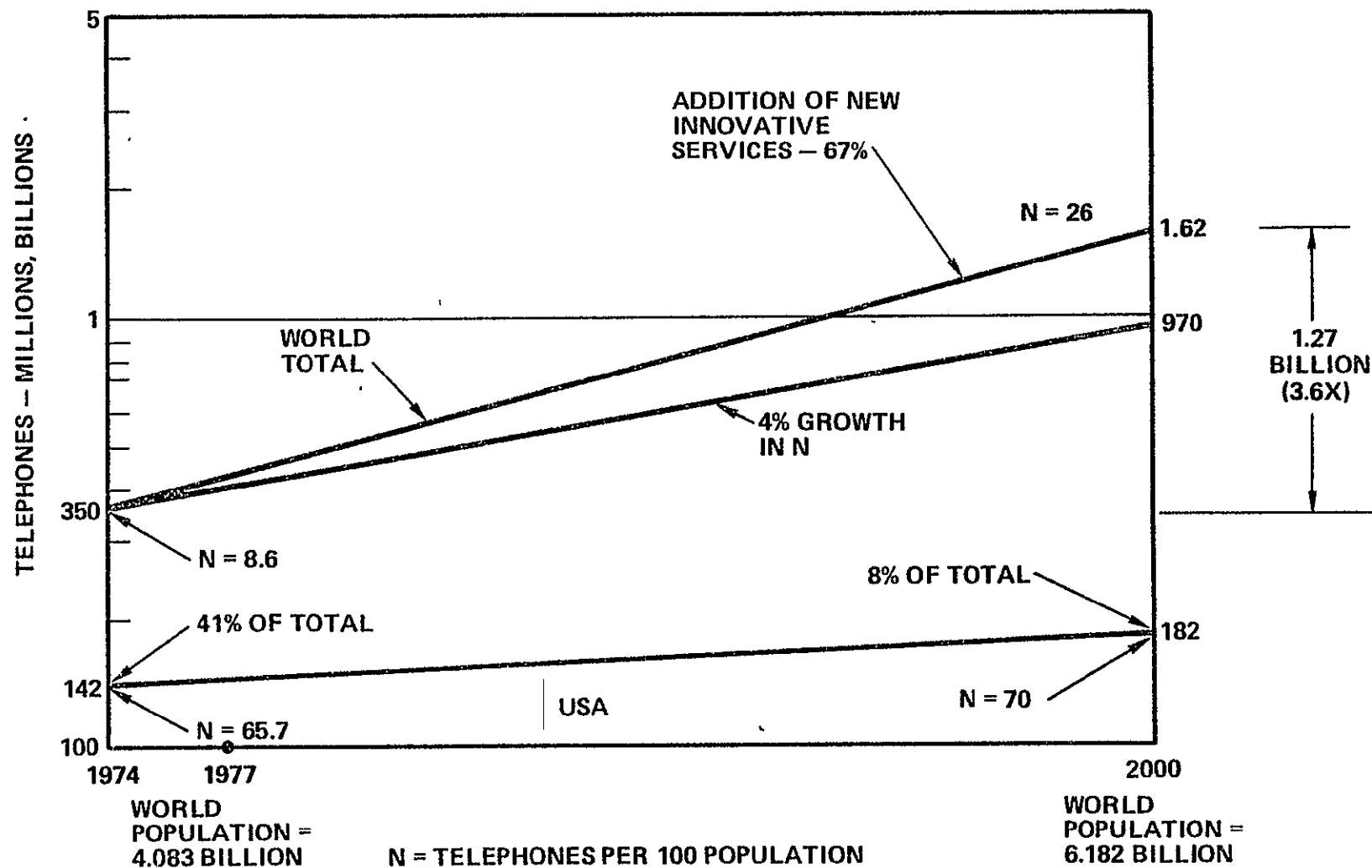
As of 1974, Department of Commerce statistics estimated a world total of 350 million telephones. At a 4% annual rate of increase (the worldwide long-term trend), by the year 2000 an additional 620 million telephones could be expected, bringing the world total to some 970 million instruments.

As stated earlier, innovative services could represent an additional 67% increase in equivalent telecommunications capacity, bringing the world total of telephones to about 1.6 billion by the year 2000. This increase represents a 3.6-fold growth in worldwide telecommunications.

The 140 million telephones in the US in 1974 (65.7 for each 100 persons) represented 41% of the world total. By the year 2000 if this statistic were merely to increase to 70 telephones for each 100 persons in the US, an additional 40 million telephones would be needed. As of 1974, the world average statistic was 8.6 telephones per 100 persons. An increase to 1.62 billion telephones as demanded by a worldwide population of over 6 billion would represent an upwards adjustment in the status quo to a figure of some 26 equivalent telephones per 100 population, a figure in fair agreement with the projection based merely on historical trends.

Demographic projections present a dramatic case for the impending worldwide increase in telecommunications facilities, which would result in strong economic incentives to both the public and private sectors of the world's economy and the further development of high-technology industries.

WORLDWIDE TELECOMMUNICATIONS GROWTH



The International Telecommunications Satellite Organization (INTELSAT) is an international legal entity in which 95 countries, 24 of which are developed nations, hold investment shares. Each country invests in proportion to its use of the system.

Before INTELSAT, the 71 developing countries had to rely on high-frequency radio for international communications. Channel capacity was limited and transmission quality was poor. The INTELSAT system now provides a large number of circuits, signals of high quality, and direct routing from one country to another.

The developing countries appreciate quality and capacity of the INTELSAT as compared to previous systems. Many have responded to the romantic appeal of participating in an international space venture. Participants in INTELSAT, must invest in earth stations, a costly effort, relatively speaking, in view of the competing demands on the limited resources of developing countries.

The telecommunications satellite does not entirely replace terrestrial links or substitute for all transmission lines and switching equipment within a town or village, but it has made long-distance signal transmission cheaper, and, by expanding communications capability, has stimulated the general economic growth of these developing nations.

SITE has demonstrated that the satellite can also reduce the time and cost of establishing new television broadcasting services. Developing countries in particular have the problems of expanding student populations, serious shortages of trained teachers, and widespread illiteracy. Television can help by providing basic instruction of a quality that would not otherwise be available. Television is a unique image-plus-sound tool for teaching reading and writing, as well as for providing vital information on health, birth control, and agricultural methods.

Television may also help unite developing nations and regions. East and West Pakistan, for example, are separated by a portion of India, and television may be the best bridge between them. Latin America possesses a much higher degree of cultural and language commonality (with the exception of Brazil) than other developing regions of the world, and television can serve as a bridge across national borders between Latin American nations. A new television service can provide, for the first time, a window to the outside world.

THE DEVELOPING COUNTRIES

SATELLITE TELECOMMUNICATIONS

EXTREMELY IMPORTANT TO DEVELOPING COUNTRIES

- CONTRIBUTES TO DOMESTIC TWO-WAY TELEPHONE SYSTEMS
- PROVIDES LOW-COST SUBSTITUTE FOR COAXIAL CABLE AND MICROWAVE RELAY
- STIMULATES GENERAL ECONOMIC DEVELOPMENT
- PROVIDES ROMANTIC APPEAL OF PARTICIPATION IN AN INTERNATIONAL SPACE VENTURE

SATELLITE BROADCASTING

CAN PROVIDE VITAL INFORMATION ON HEALTH, POPULATION CONTROL, AND AGRICULTURE

- REDUCES THE COST OF ESTABLISHING NEW TELEVISION SERVICES IN THE DEVELOPING COUNTRIES

- NEW SERVICES NEED NOT PROVIDE A LARGE NUMBER OF CHANNELS
- HELPS OFFSET THE TEACHER SHORTAGE
- HELPS UNITE DEVELOPING NATIONS AND REGIONS
- PROVIDES A WINDOW TO THE WORLD

SATELLITE TELECOMMUNICATIONS AND BROADCASTING

BEST SERVED BY LOW-COST EARTH STATIONS - THE PRINCIPLE OF **COMPLEXITY INVERSION**

SOURCE: COMMUNICATING BY SATELLITE,
P. L. LASKIN, TWENTIETH CENTURY FUND
TASK FORCE, NEW YORK, 1969

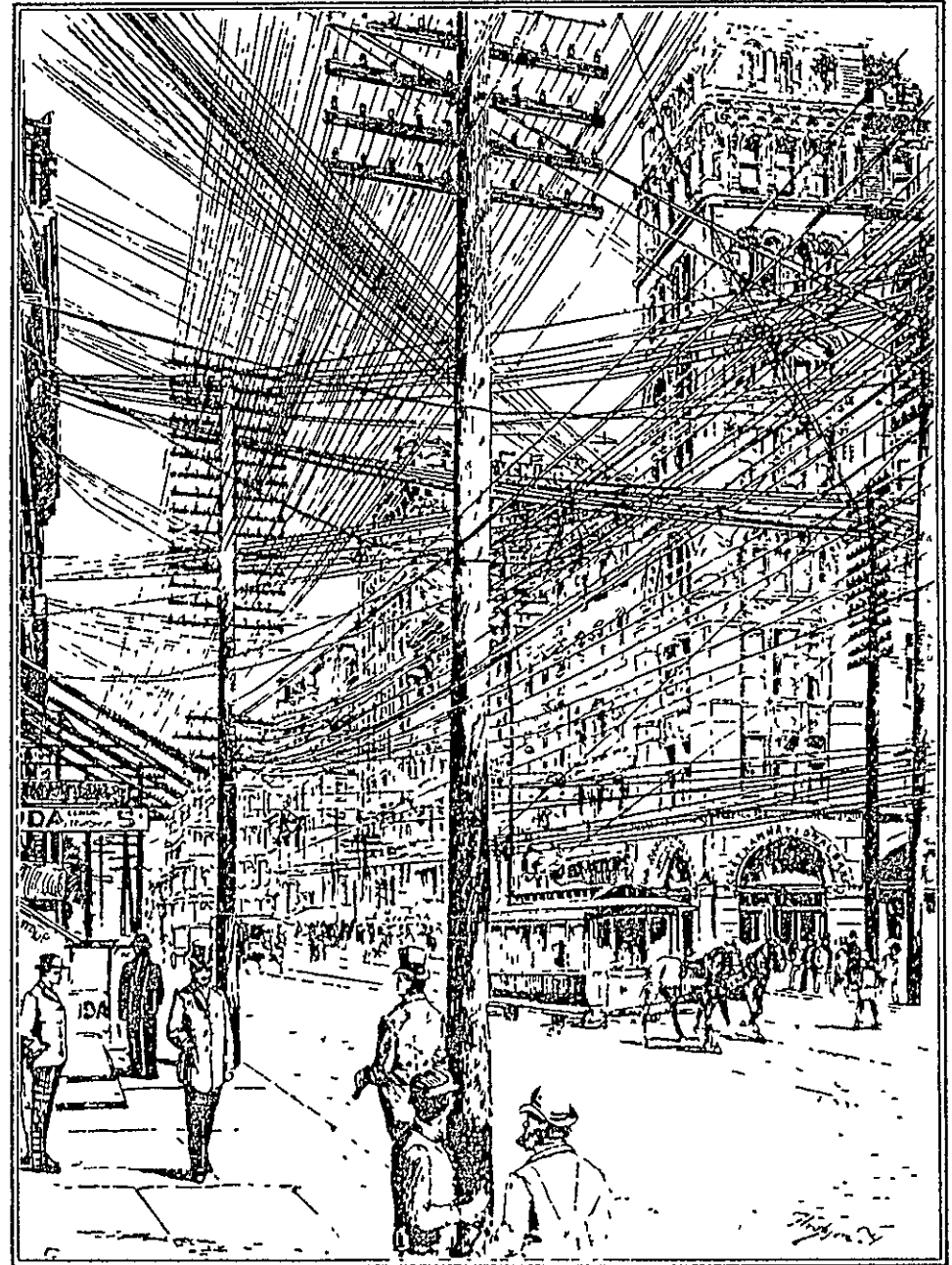
One of the most vivid illustrations of how an advance in technology permitted a vast increase in availability of telecommunications is the Bell Telephone System's experience in New York City. In the year 1890, telephone service for Manhattan had grown to the point where some 8,000 telephones were in service. All the connections between subscribers and the central offices were supplied by open-wire pole lines.

By the year 1940, in Manhattan, the number of telephones had grown to about 1 million instruments. Virtually all the open wires had been replaced by multiple conductor cables, most of which were underground. Without the development of the cable technology, followed in the 1950's and 1960's by coaxial cable and microwave relay capability, the development of New York's and the nation's telephone capability would have ceased.

TELEPHONE WIRES IN NEW YORK IN 1890

POLE LINES IN NEW YORK AT A TIME WHEN THERE WERE ABOUT 8,000 TELEPHONES ON MANHATTAN ISLAND. WITHOUT THE RESEARCH THAT PRODUCED UNDERGROUND CABLES, AND THEN LATER MICRO-WAVE RELAYS, THE GROWTH OF THE TELEPHONE SYSTEM WOULD HAVE STOPPED.

SOURCE: THE BELL TELEPHONE SYSTEM,
A. W. PAGE, 1940



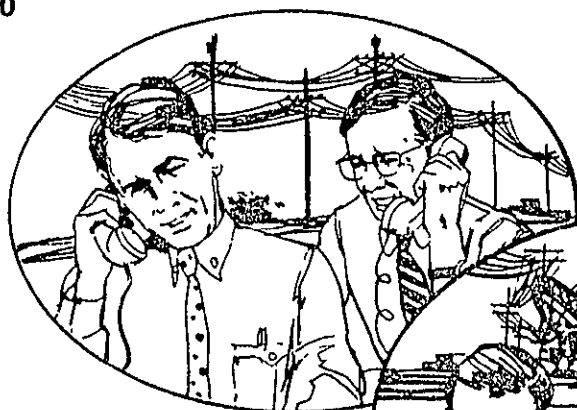
The implementation of a new concept for personal communications, using advanced space technology, could revolutionize the communications field just as cable development did. Personal communications are of tremendous social, political, and economic importance. All aspects of business, government, and family life are largely dependent on reliable long-distance voice contact. To extend these services to broadening segments of the world's population, continuing advances in the reliability, economy, and availability of telecommunications are a must.

Today's telecommunications satellite systems still rely on extensive, complex, and costly ground facilities linking individual subscribers by wire to centralized locations where extensive switching and routing operations take place. With the advent of communications satellites for longer-distance routing, significant transmission economies were realized even though major fixed ground complexes were still used.

The new space-oriented concept provides for "complexity inversion," an approach where more of the complex elements and functions are placed in space rather than on the ground. With this new approach, a system can provide entirely new modes of information transfer, opening up new dimensions of public service benefits. Such benefits as improved health care information, emergency services, navigation applications, and broadcasting could become realities.

COMPLEXITY INVERSION FOR FUTURE PERSONAL COMMUNICATIONS

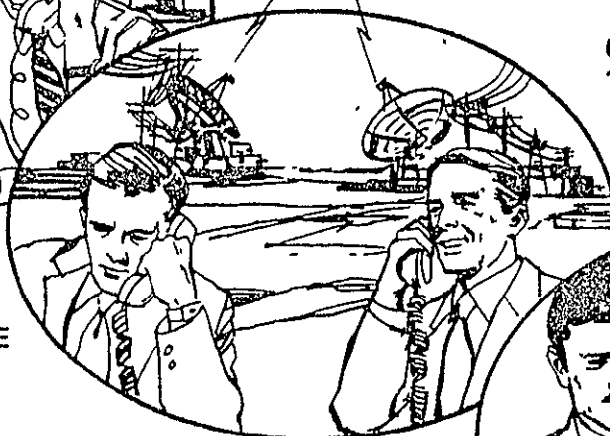
CIRCA
1950



- HEAVY TIME SHARING OF LONG DISTANCE CIRCUITS
- LOW POWER SIMPLE SATELLITES

- EXTENSIVE SWITCHING AND MULTIPLEXING
- HIGH POWER — COMPLEXITY SPACE SYSTEMS

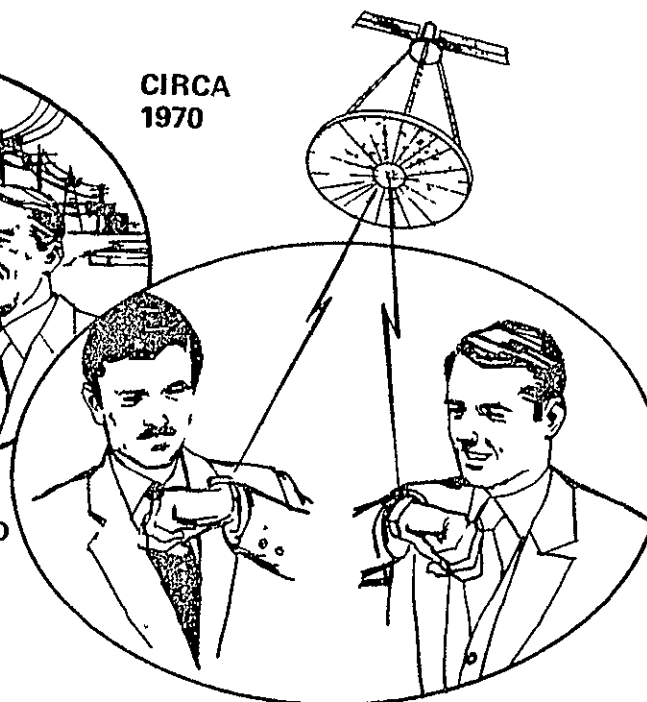
CIRCA
1970



- INDIVIDUAL HARD WIRED TO LOCAL EXCHANGE
- EXTENSIVE INTER-EXCHANGE SWITCHING
- HEAVY DEPENDENCY ON LONG DISTANCE LAND LINES
- TIME SHARING OF INDIVIDUAL CIRCUITS AT A MINIMUM
- HEAVY INVESTMENT IN GROUND FACILITIES

- INDIVIDUAL HARD WIRED TO LOCAL EXCHANGE
- EXTENSIVE INTER-EXCHANGE SWITCHING
- LIMITED NUMBER OF FIXED ACCESS HEAVY TRAFFIC TERMINALS

CIRCA
1990



- INDIVIDUAL-TO-INDIVIDUAL DIRECT ACCESS THROUGH SINGLE EXCHANGE
- LOW POWER-INEXPENSIVE USER EQUIPMENT

The best authority projects a world population increase of 2 billion over the next 23 years. Short of a catastrophe of worldwide proportions, this increase in population represents real increase in market demand and therefore in gross national production of between \$50 and \$100 billion annually for the communications-related industries.

To satisfy this increase in demand, by the year 2000 it will be necessary to manufacture additional equipment and build new plants. The industry average suggests that about two dollars of plant and equipment are required to produce one dollar of gross revenue. Accordingly, in order to meet the projected increase in demand, the new plant and equipment which will be required will represent an added capital investment of between \$100 and \$200 billion. The developed and the developing nations must share the burden of this increase as well as benefit from the return on investment that can be expected.

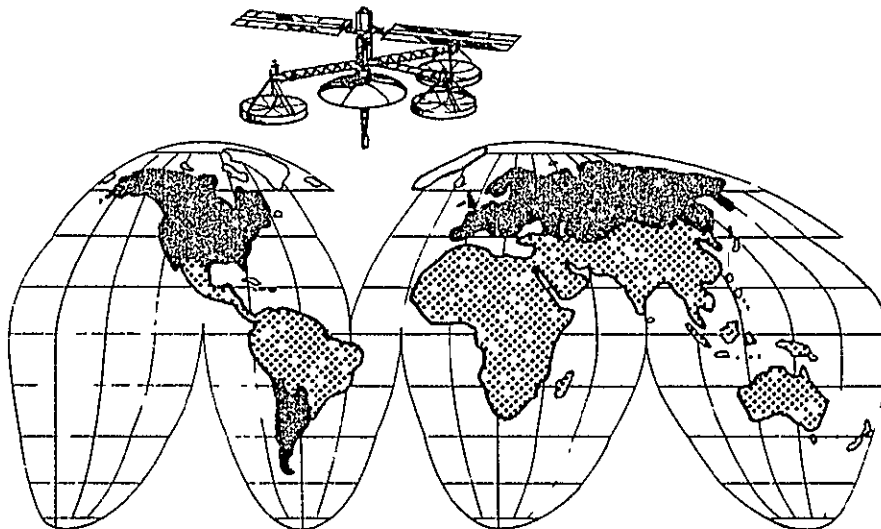
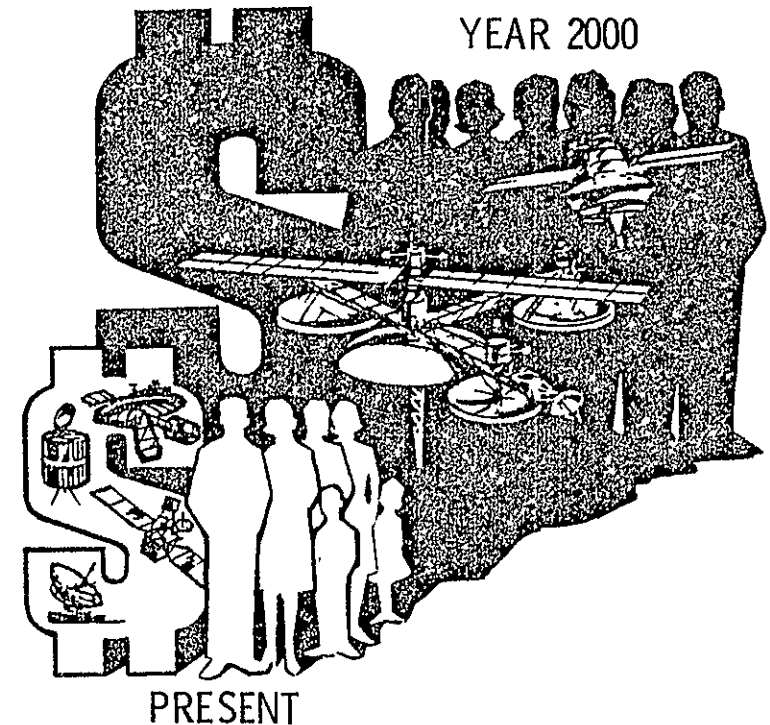
In the US, the industry rate of replacement of telecommunications plant and equipment is about 6% per year. Advances in technology require economically and functionally obsolete systems to be replaced every 17 years. On this basis, the new plant and equipment to meet worldwide needs by the year 2000 represent assets that do not exist today.

New technology can doubly contribute to the general development of both developed and developing nations. The development is "a necessary and irreversible process: from the viewpoint both of the hopes of backwards people and of the selfish interests of the advanced."¹ Developing nations can provide domestic production of simple, low-cost subscriber equipment and earth stations that would provide the revenue with which to lease the linking circuits and services from high-technology, economically favorable telecommunications satellites. On the other hand, the developed nations, and in particular the US, can benefit by providing these needed services.

1. World Order, Rationality, and Socioeconomic Development, H. Jaguaribe, DAEDALUS, Volume 95

COMMENTS ON WORLD MARKET FOR INFORMATION SERVICES

- INCREASE IN POULATION BY 2000 WILL GENERATE NEW MARKETS IN COMMUNICATIONS RELATED EQUIPMENT AND SERVICES OF \$50 TO \$100 BILLION PER YEAR
- ADDITIONAL INVESTMENT IN PLANT AND EQUIPMENT EQUATES TO \$100 TO \$200 BILLION BY 2000
- DEVELOPING NATIONS ADVANCE SOCIOECONOMICALLY THROUGH DOMESTIC PRODUCTION, USE OF LOW-COST EARTH STATIONS AND LEASING CIRCUITS FROM HIGH-TECHNOLOGY TELECOMMUNICATIONS SATELLITES



- U. S. AND DEVELOPED NATIONS BENEFIT BY PROVIDING NEW SPACE TECHNOLOGY AND SYSTEMS TO DEVELOPING NATIONS

■ DEVELOPED COUNTRIES
 ■ DEVELOPING COUNTRIES
 ■ SPARSELY INHABITED ARCTIC ISLANDS

COMMUNICATION EXPENDITURES

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The financial reports of the two major US telephone operating companies reveal some basic economics of telecommunications. Combined, American Telephone and Telegraph Company (the Bell System) and General Telephone and Electronics Corporation (GTE) represent over 90% of the public service provided in the country.

The two companies, servicing over 135 million telephones, have combined assets of property, plant, and equipment totalling over \$86 billion. The net investment in plant per telephone for the Bell System is about \$625, for GTE it is \$690. The combined revenue from telephone operations is \$36.5 billion. The revenue per telephone amounts to \$270 for the Bell System and \$250 for GTE.

The plant and equipment average replacement rates are similar for the two companies. The plant is replaced in total every 17 years. One characteristic that sets this industry apart from most is the extent of capital investment required each year to meet the public's present and future needs. Facilities must be in place when and where public demand for service dictates.

A large portion of these capital expenditures is directed toward replacing switching equipment with newer advanced-technology high-speed electronic systems. Current trends are characterized by two new capabilities: (1) larger and advanced electronic switching systems that can process many more functions (4 x for Bell) than the largest electromechanical machines, and (2) smaller electronic switching systems designed to monitor their own operations, diagnose troubles, and, unlike the larger systems, be assembled, tested, shipped, and installed as a single unit.

Bell and GTE jointly operate a satellite system for certain domestic long-distance telephone service. The system presently consists of seven earth stations and two COMSTAR satellites leased from COMSAT General Corporation. The system, which will have the capacity to handle nearly 29,000 simultaneous conversations, involves a nationwide network servicing the 48 contiguous states and Hawaii, supplementing the microwave and traditional cable installations. Both companies have extensive research and development programs with strong emphasis on innovation. For example, as a result of testing and evaluating lightwave communications, the Bell System will install an experimental system in Chicago that will be used for voice, data, and Picturephone*. The heart of the system is a cable 1/2-inch in diameter containing 144 glass fibers that can carry the equivalent of nearly 50,000 telephone calls simultaneously. Similarly, work at GTE is focused on such techniques as all-digital switching systems, utilization of unused high-frequency radio transmission bands to carry long-distance traffic over communications satellites, and a new-generation of long-life batteries.

*Registered trademark of AT&T.

TELECOMMUNICATION ECONOMICS

35782

ITEM	DOLLARS IN THOUSANDS		
	AT&T	GTE	TOTAL
PROPERTY, PLANT AND EQUIPMENT	94,167,483	12,903,594	107,071,077
ACCUMULATED DEPRECIATION	(18,245,477)	(2,685,225)	(20,930,702)
NET PLANT	75,922,006	10,218,369	86,140,375
NET PLANT PER TELEPHONE	625	690	650 AVERAGE
TELEPHONE OPERATIONS REVENUE	32,815,582	3,688,659	36,504,241
REVENUE PER TELEPHONE	270	250	260 AVERAGE
EXPENSE			
MAINTENANCE	6,624,782	681,639	7,306,421
DEPRECIATION	4,483,906	645,134	5,129,040
RESEARCH AND DEVELOPMENT	249,867	106,000 (EST)	355,867
PLANT REPLACEMENT RATE/ AVERAGE LIFE - YEARS	6%/17	6%/16	6%/16.8

SOURCE: 1976 ANNUAL REPORTS, AMER TEL & TEL, AND GEN TEL & ELECTRONICS

Typically, the plant and equipment required to provide telecommunications services can be categorized within four major groups. The subscribers equipment satisfies the immediate and personal needs of the users. This familiar equipment includes the basic instrument, of which a wide variety of styles and types are available, and the other apparatus, wire, and cables that are situated in the domicile, office, or plant of the individual subscriber. Also included in this group would be whatever switching and call directing equipment is needed to satisfy the requirements of subscribers with several instruments and incoming trunk lines. From the standpoint of invested capital, the subscriber equipment represents about 17% of the total plant.

The second group is the central office equipment, which services a number of nearby subscribers. In addition to the switching functions, the central office also serves an accounting function for billing purposes. Some 26% of the total plant is devoted to the central office.

The third group consists of the underground and aerial plant that link the individual subscribers and the central offices to form the network complex. Forty-six percent of the total plant is devoted to this group, which consists of the wires, cables, microwave radio relay stations, earth stations, and space satellites.

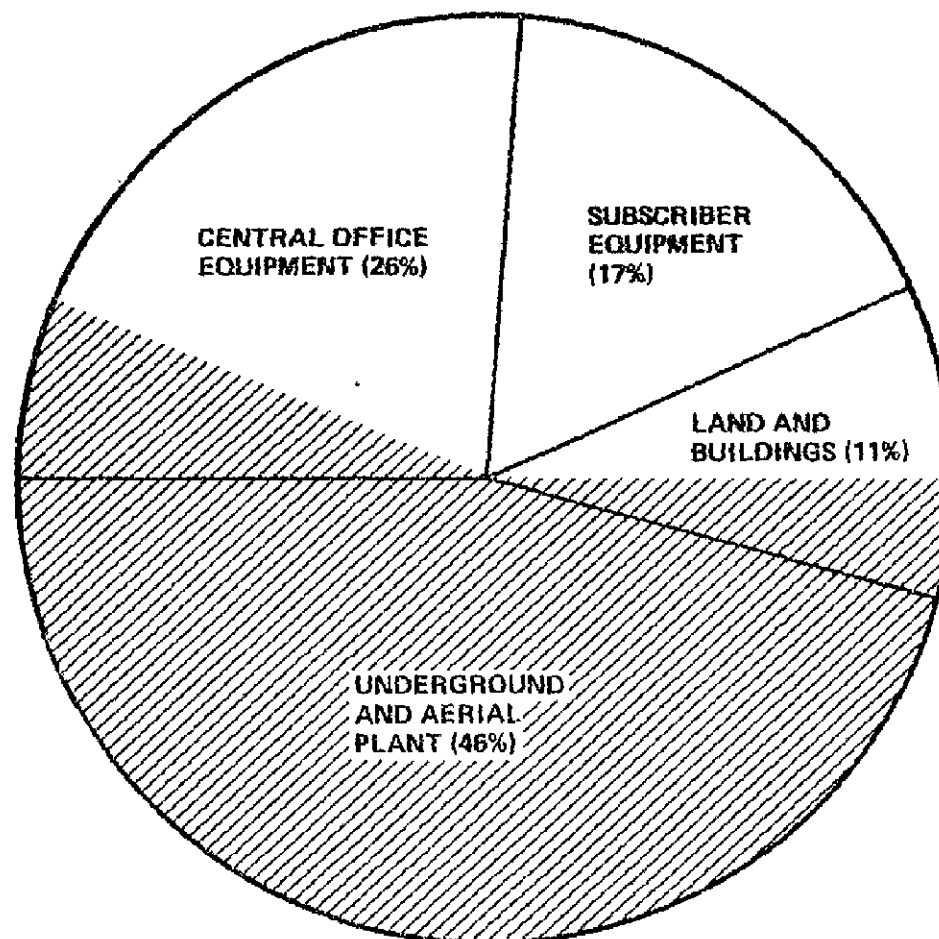
About 11% of the assets are represented by the real estate needed to house the apparatus and provide office and working space for the employees of the operating company. These lands and buildings would typically be at various stages of development and geographically dispersed.

With the "complexity inversion" approach the satellite would represent a considerably larger proportion of the system. If the satellite were leased, as is the case with Bell and GTE in their arrangements with COMSAT, the amount of fixed assets necessary to be carried by a telecommunications operating company could be reduced considerably. The space system could perform additional complex functions such as automated switching, routing, and accounting. The portion of the plant and equipment which would be required on the ground could be made less complex. For example, the central office equipment could be made simpler, the subscriber equipment could be less costly, and the investment in real estate could be lessened. In all, the per unit investment by the operators could be reduced to the point where many smaller independent telecommunication companies could become economically and financially feasible.

COMPLEXITY INVERSION OFFERS BROADENED SERVICES AT LOWER PER UNIT INVESTMENT TO USERS

 ELEMENTS
REPLACED BY LEASED
PLANT IN SPACE

- REQUIRES LESS COMPLEX
CENTRAL OFFICE
EQUIPMENT
- UTILIZES LOWER
COST SUBSCRIBER
EQUIPMENT
- REDUCES INVESTMENT
IN FIXED ASSETS



The original privately financed earth station for satellite telecommunications was designed and built by Bell Telephone Laboratories in the early 1960's. This experimental earth station using the TELSTAR satellite demonstrated for the first time the technical and economic feasibility of systems that had been proposed by Arthur C. Clarke in the 1940's. Located at Andover, Maine, this station represented an investment by the Bell System in excess of \$10 million; the cost was not a determining factor insofar as the economic viability of the project was concerned.

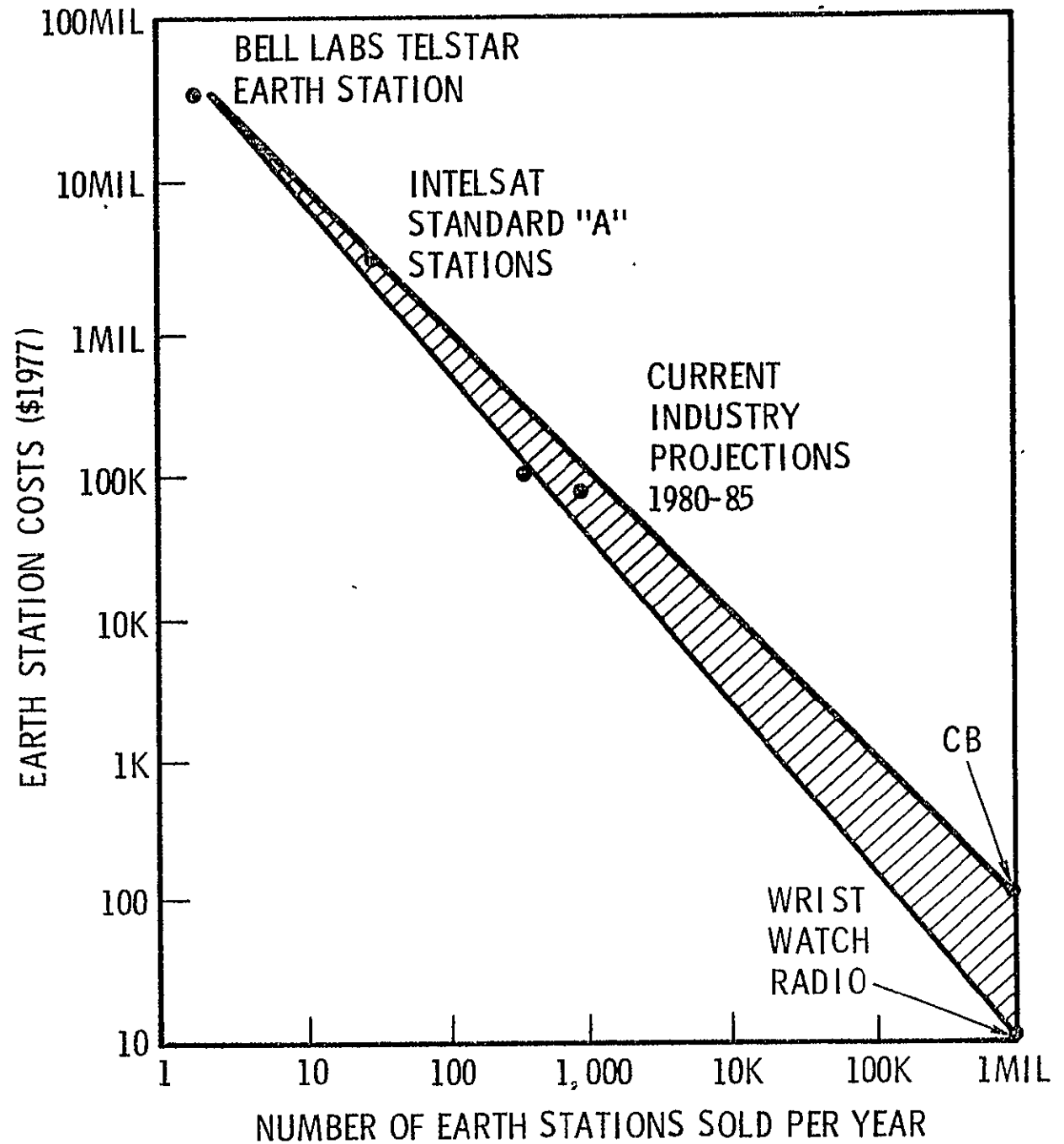
In the first year (1965), INTELSAT brought on-line five earth stations to establish the initial network connecting the five participating countries. During 1969, 27 earth stations were added to the system, bringing the total to 36 stations and 24 countries. These stations cost on the order of \$5 million. Again, the cost of the stations was not a dominant factor in the demand equation.

Advance in technology mainly in the area of initial signal application and an accelerated demand for earth stations has come to the point where stations can now be purchased essentially as standard off-the-shelf items for less than \$100,000. The market has reached an elastic point where, as the cost is reduced (supply increased), the demand rises. Recent industry projections for the 1985 time period forecast sales in the neighborhood of 8,000 stations at an average cost of around \$70,000.

Three major trends are slimming down the cost of earth stations to meet grassroot demands. Less complex, less expensive earth terminals are becoming possible because higher frequencies are being utilized, satellite power levels have been increased, and the use-oriented terminals are cheaper. The ultimate demand might be experienced by the complexity-inverted personal communications system concept where the earth station would be essentially a wristwatch-sized terminal. At \$10.00 each, these devices could easily reach a market of 1 million annually. The current market for citizen-band equipment, a present technology substitute for traditional telecommunications, at an average cost to the consumer of about \$100, exceeds 1 million units per annum.

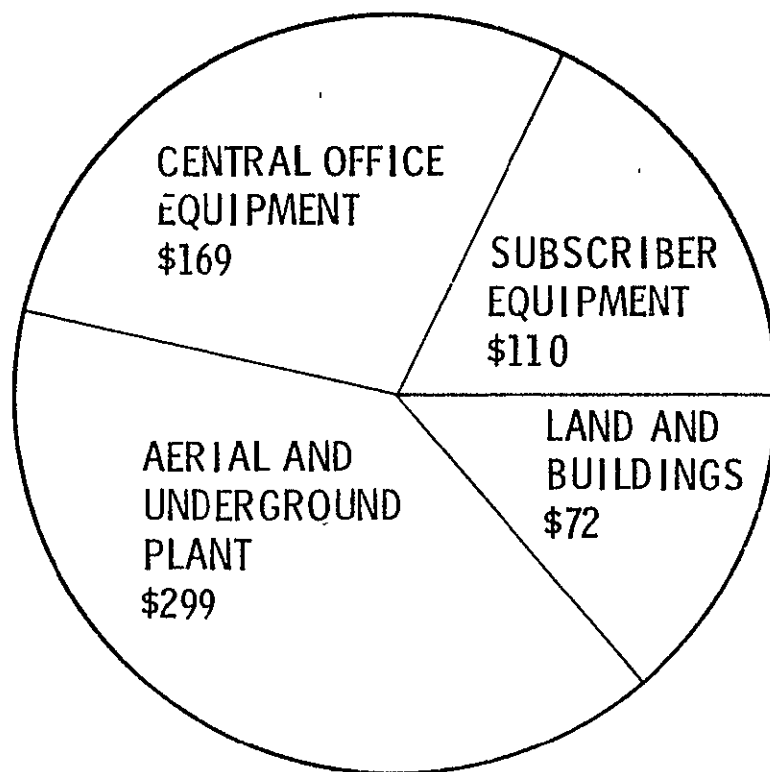
ELASTICITY OF DEMAND FOR EARTH STATIONS IS FUNCTION OF COSTS

SOURCE: MICROWAVE
SYSTEMS NEWS, VOL 7
NO. 3, MARCH 1977,
pp 21, 30, 61, 84

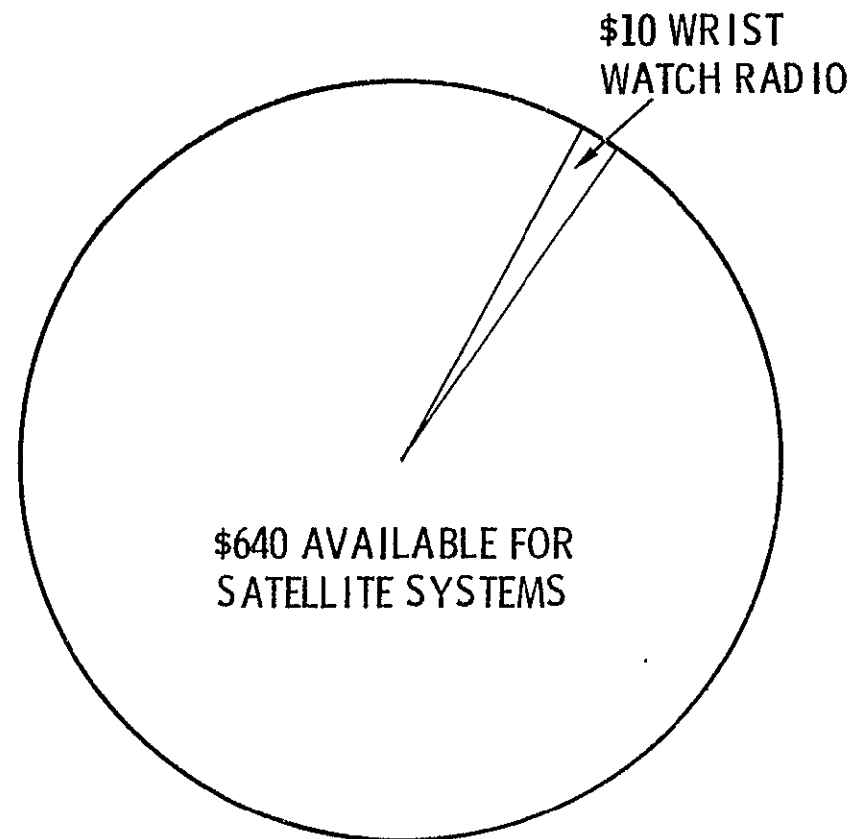


The average plant and equipment investment required per telephone, as experienced by the Bell System and GTE, is about \$650. The distribution within the four major groups for conventional telephone systems are \$110 for subscriber equipment, \$169 for central office equipment, \$299 for aerial and underground plant, and \$72 for land and buildings. Assuming a ratio of \$650 of fixed assets per telephone, a \$10 wristwatch radio for a personal communications system would allow \$640 to be invested in other plant and equipment systems. If the complexity inversion were complete, that is, no facilities other than the satellite systems required, the figure of \$640 per user would be available for investment in the space-based system.

INVESTMENT PER SUBSCRIBER FOR NEW SERVICES



GROUND BASED CONVENTIONAL APPROACH
(ASSUMING AN AVERAGE OF \$650 OF PLANT
REQUIRED PER TELEPHONE)



COMPLEXITY INVERSION

One concept for a personal telecommunications satellite is shown on the facing chart. This system incorporates a 27-meter aperture multiple-beam-lens with 1,000 individual feed horns. Working at several select frequencies, the system could service as many as 25 million individual subscribers. A preliminary estimate of the development and deployment cost of the satellite is \$280 million.¹ Assuming that the system would exhibit a 7-year service life, the investment cost per year of operation would be \$40 million.

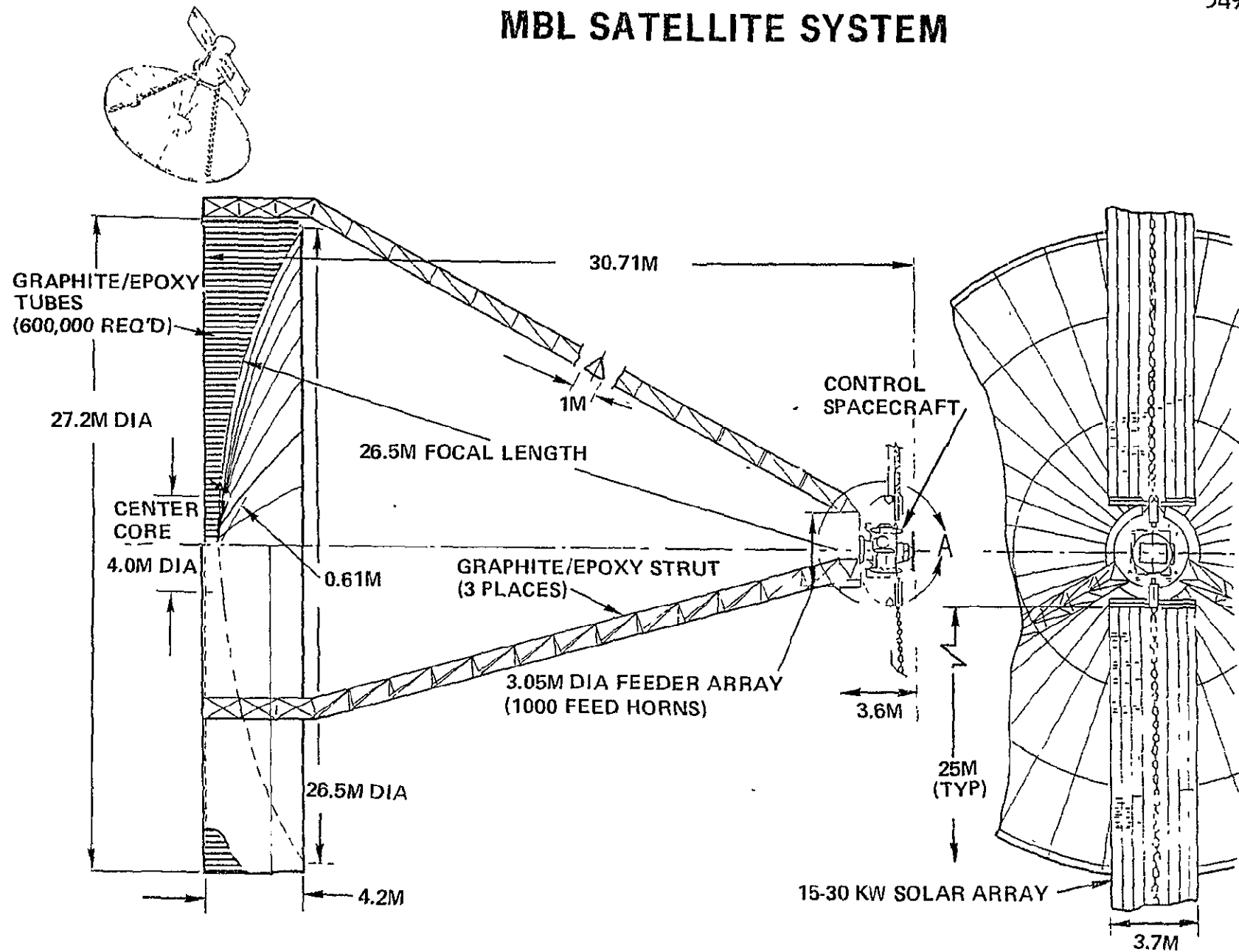
If the satellite system represented \$640 allocated to each subscriber, and also if each subscriber provided his own earth station, as discussed previously, then only 438,000 subscribers would be needed to maintain the same ratio of plant and equipment as is now experienced by conventional ground-based telecommunications systems. If the only operational cost were that of the satellite system, namely \$40 million annually, then a revenue of less than \$100 per subscriber would just recapture the initial investment. At a service charge of say \$130 per subscriber*, the return on the investment (ROI) would be over 40%. ROI's of 40% are sufficient to attract venture capital, providing that the project risks and uncertainties are well understood.

*By way of comparison the Bell System received operating revenue of about \$270 per average telephone during 1976.

1. Space Station Systems Analysis Study - July 1977 - McDonnell Douglas Astronautics Company Contract NAS 9-14958

TYPICAL COMMUNICATIONS SERVICES MBL SATELLITE SYSTEM

34960



The economic considerations presented in the text matching the previous chart are repeated on the facing chart. There is sufficient uncertainty in the new technology represented by the complexity inversion approach to make a case for a clear-cut decision impossible at this time. A telecommunications satellite of the size and proportions presented would require firm knowledge of space construction techniques based upon experience and feasibility demonstrations before a business commitment would become a reality.

The bare-bones economics do suggest, however, that if the uncertainties were indeed reduced, private investment in future "complexity-inversion" systems would be a viable economical venture.

BASIC ECONOMICS OF PERSONAL COMMUNICATIONS

ESTIMATE TOTAL COST IS \$280 MILLION FOR SPACE SYSTEM WHICH COULD SERVICE UP TO 25 MILLION SUBSCRIBERS

AT \$650 PER SUBSCRIBER, A \$280 MILLION SPACE PLANT COULD BE SUPPORTED BY ABOUT 430,000 USERS

AT A USER CHARGE FOR THE SERVICE OF \$130 PER YEAR AND ASSUMING A 7-YEAR USEFUL SERVICE LIFE THE SYSTEM WOULD GROSS A 40% RETURN ON INVESTMENT

IN CONTRAST AT&T CHARGES \$230 PER USER AND REALIZES A RETURN ON INVESTMENT OF 16% BEFORE TAXES AND 5% AT NET INCOME

BASIC ECONOMICS OF THE COMPLEXITY INVERSION APPROACH WOULD REPRESENT A STRONG INCENTIVE TO ATTRACT PRIVATE VENTURE CAPITAL

CURRENT CAPABILITIES

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By the year 1980, over 40 telecommunications satellites will occupy the longitudinal positions in geosynchronous equatorial orbit as shown on the facing chart. These satellites will either service dedicated domestic needs, such as COMSTAR, which is part of the Bell System and GTE long-distance network, or be part of the global INTELSAT system.

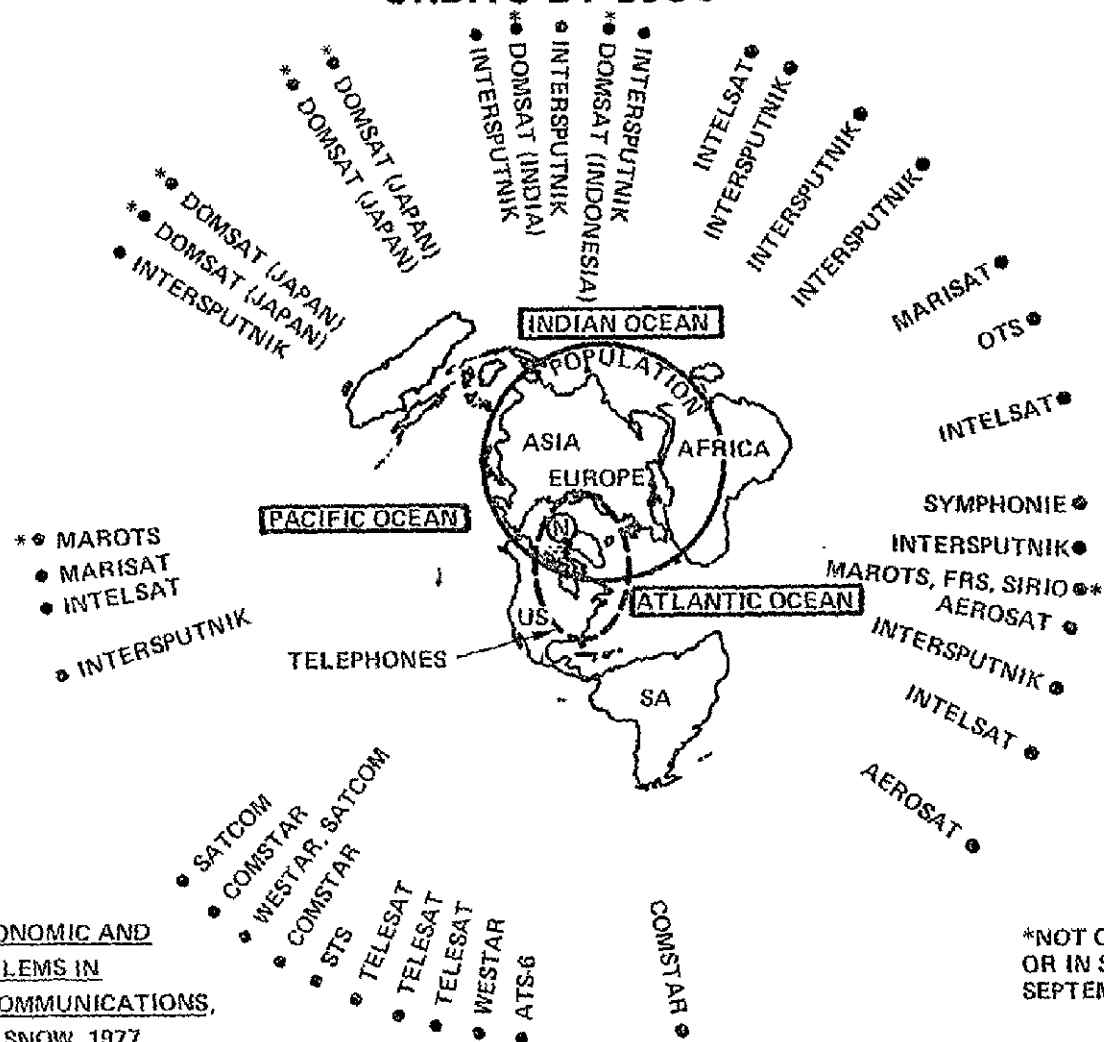
Also shown on the chart as represented by the circle eccentric about the North Pole is the relative distribution of world population. It is a well known fact, as evidenced by the circle, that the larger proportion of world population exists in the developing regions of Asia and Africa.

In addition to the population circle, an eclipse, likewise eccentric about the North Pole, represents the number of telephones in use in the various geographical regions of the world. An imbalance exists between the population circle and the telephone eclipse. That is, the status quo favors the less populated, more developed regions of the world.

Any adjustment in the status quo to rectify the imbalance will necessitate additional satellites mainly over the 120° longitudinal sector spanning Western Europe eastward to the Malay Peninsula. It is within this sector that severe future orbital crowding can be expected and innovative new approaches will be required to solve the potential problems and provide for the projected needs.

COMMUNICATION SATELLITES IN GEOSTATIONARY ORBITS BY 1980

35788



Continued growth of the INTELSAT system is of vital importance to the worldwide network of telecommunications satellites. There are several distinguishing characteristics inherent in the historical development and future plans for the system that are of significance here.

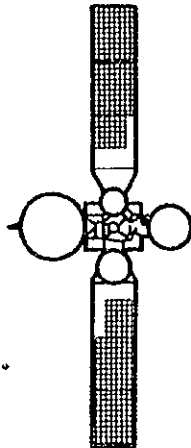
Each of the five generations of INTELSAT satellites incorporates a significant new advance in satellite communications technology.

1. INTELSAT I (Early Bird), the world's first commercial communications satellite, was placed in service in June 1965. It established the first satellite pathway between the United States and Europe and made live transoceanic TV possible for the first time.
2. INTELSAT II satellites, placed over the Atlantic and Pacific Oceans during 1967, introduced a multipoint communications capability and extended satellite coverage to more than two-thirds of the world.
3. INTELSAT III satellites established the global system launched in 1968 and placed in service over the Atlantic, Pacific, and Indian Oceans. They also introduced the simultaneous transmission of all forms of communication - telephone, television, telex, data, and facsimile.
4. INTELSAT IV satellites, placed in service between 1971 and 1975, further expanded the global system. They made it even more flexible and versatile, and introduced the spot beam concept, a concentration of satellite communications capability on small areas.
5. INTELSAT IV-A satellites, placed in service beginning in 1976, take spot beam technology one step further. They apply it to frequency reuse to conserve the limited bands allocated for sharing by satellite and terrestrial communications.

Designed to meet demands for global system service in the early 1980's, the INTELSAT V series will comprise seven satellites, each able to carry 12,000 telephone conversations simultaneously, plus television. The new satellite representing the latest in current commercial technology will be body stabilized as opposed to the spinning design of the others in the series.

FIVE GENERATIONS OF COMMUNICATIONS SATELLITES

35789

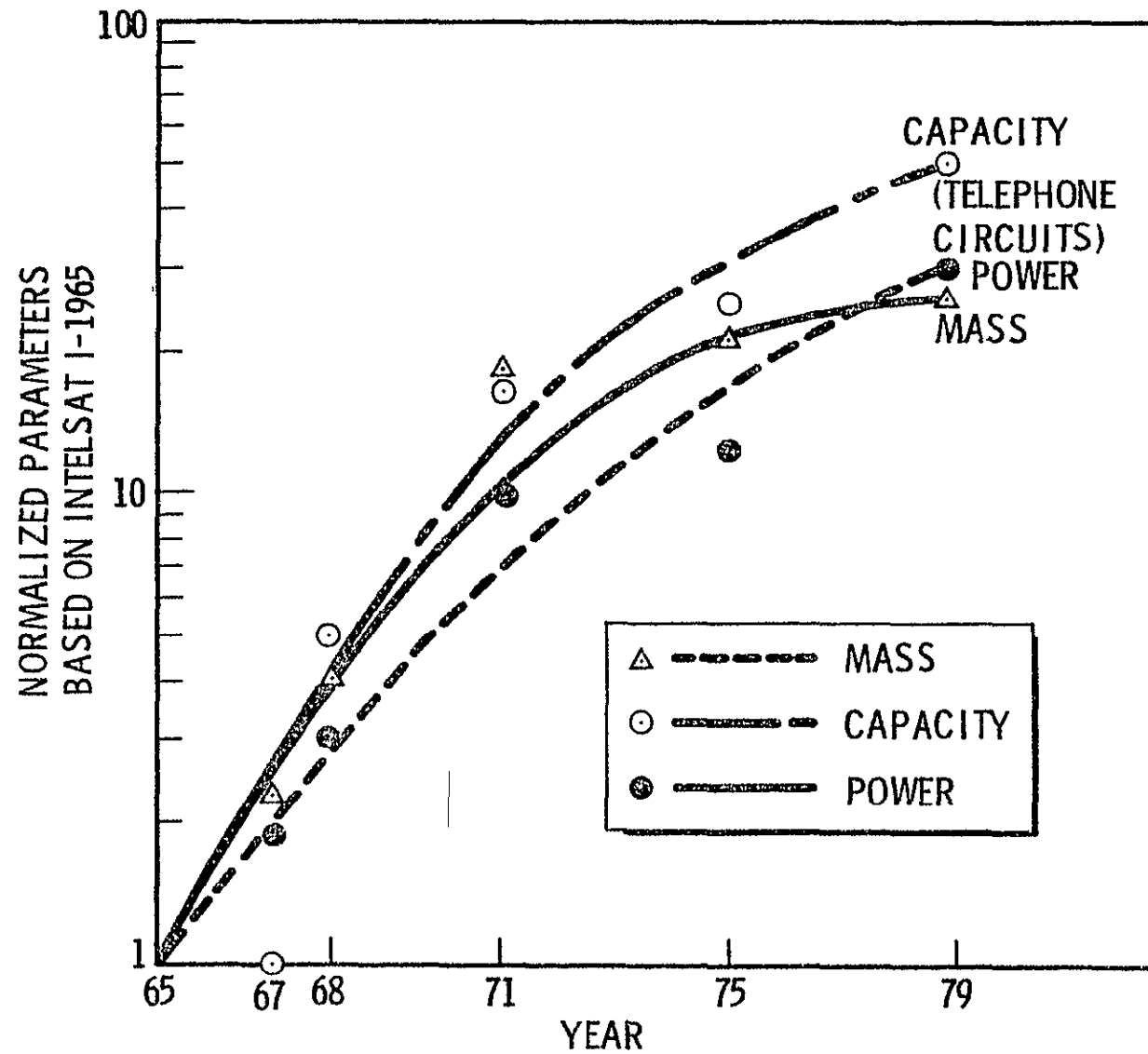
	INTELSAT I 	INTELSAT II 	INTELSAT III 	INTELSAT IV 	INTELSAT IV-A 	INTELSAT V 
YEAR OF FIRST LAUNCH	1965	1967	1968	1971	1975	1979
HEIGHT (CM)	60	67	104	528	590	1570
WEIGHT IN ORBIT (KG)	38	86	152	700	790	967
ELECTRICAL POWER (KW)	0.04	0.075	0.120	0.400	0.500	1.200
CAPACITY (TELEPHONE CIRCUITS)	240	240	1,200	4,000	6,000	12,000
DESIGN LIFETIME (YEARS)	1.5	3	5	7	7	7
INVESTMENT COST PER CIRCUIT YEAR	\$32,500	\$11,400	\$2,000	\$1,200	\$1,100	\$800

SOURCE: GLOBAL SATELLITE COMMUNICATIONS, B. I. EDELSON,
SCIENTIFIC AMERICAN, FEBRUARY, 1977

The technological advance of the INTELSAT series is represented on the facing chart. Normalizing the capabilities and characteristics of "early bird" to unity, per unit mass, circuit capacity and power are plotted versus year of launch for each generation of satellite. In terms of the parameter of capacity, a 50-fold increase occurs from INTELSAT I to INTELSAT V. Of more importance economically, a decrease in investment cost per circuit year, as shown on the previous chart, from \$32,500 to \$800 is a measure of the improvement in specific performance for the series.

Although the economic consequences of improvement in INTELSAT cost performance are startling, it must be remembered that the many users (95 countries as of February 1, 1977) still have invested heavily in earth stations. As of December 31, 1976, 126 stations, each owned and operated by telecommunications entities in the countries where they are located, were in service. Even though the trend has been for each successive generation to be characterized by better performance, lower cost, and simplified operations and maintenance, the major investment allocation has been in the ground-based plant and equipment and not in the satellite portion of the total system. The hard economics of the situation has been and remains that the satellite investment cost allocation is small enough relatively speaking that the number of satellites in service are not a constraining financial consideration in total system implementation. The number of satellites currently in service or planned for the future from financial considerations alone can be set at whatever number is required to meet the technical requirements of the overall system. The real issue (as will be discussed later) is the number of satellites regardless of cost that can be crowded into the limited number of available parking slots.

INTELSAT GROWTH PATTERN



36521

DEMAND GAP

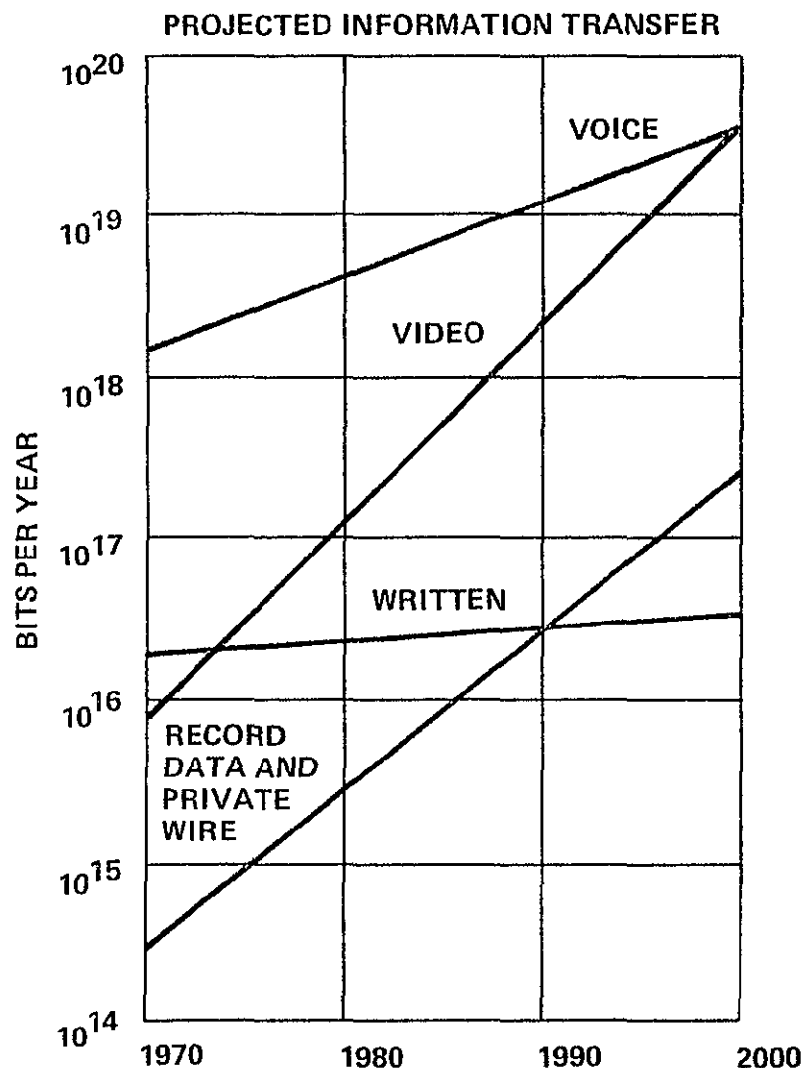
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Two studies independently have projected growth of information transfer requirements and telecommunications traffic. The first of the two chronologically was conducted by Stanford Research Institute (SRI) in 1970. This study reports growth projected for voice, video, written material, and records expressed in terms of bits per year. As shown on the left-hand plot, the average growth shows an increase of about three orders of magnitude over the 30-year span to 2000. This represents an annual rate of increase of about 26%.

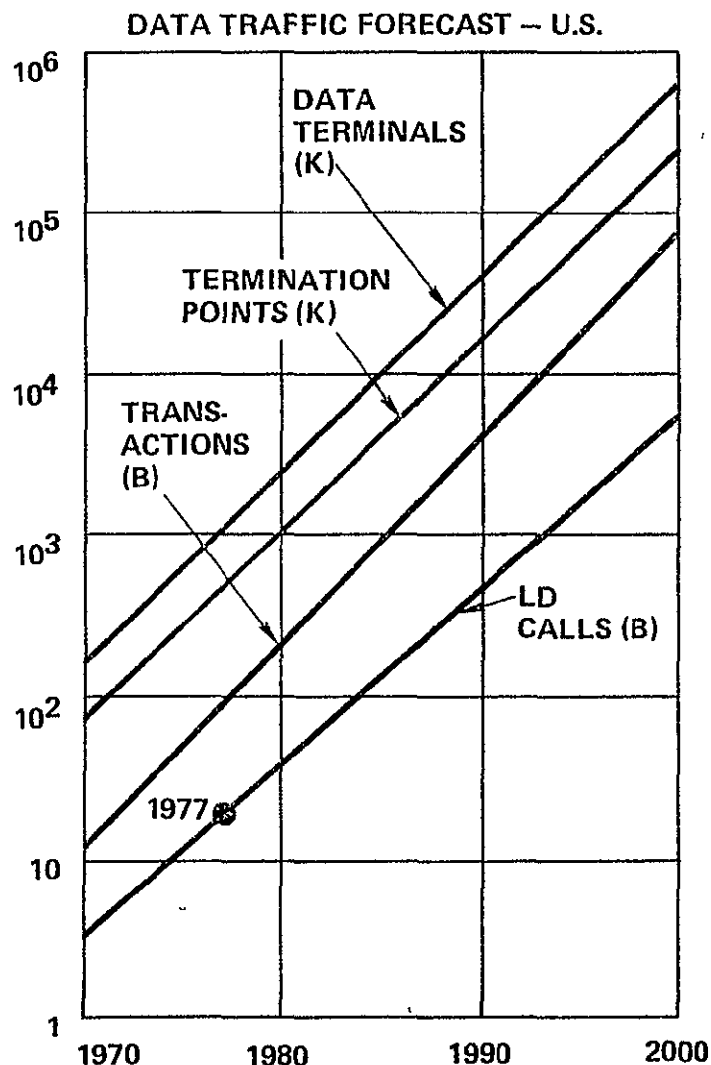
In 1973, the Organization for Economic Cooperation and Development (OCED) completed a study of data traffic for computers and telecommunications. This study concluded that the growth of data terminals, termination point, transactions, and long-distance telephone calls would increase as shown on the right-hand portion of the facing chart. Department of Commerce 1977 projection for long-distance telephone calls correlates well with the 1973 OCED findings. Again, the growth rate projections approximate the SRI forecast of an average annual rate of some 26% increase. For the purpose of this investigation, the projected increase in telecommunications demand was taken at the 26% annual figure.

DATA PROJECTIONS AND TELECOMMUNICATIONS TRAFFIC - DOMESTIC

35271A



SOURCE: A STUDY OF TRENDS IN THE DEMAND FOR INFORMATION TRANSFER, R. W. HOUGH ET AL, SRI, 1970

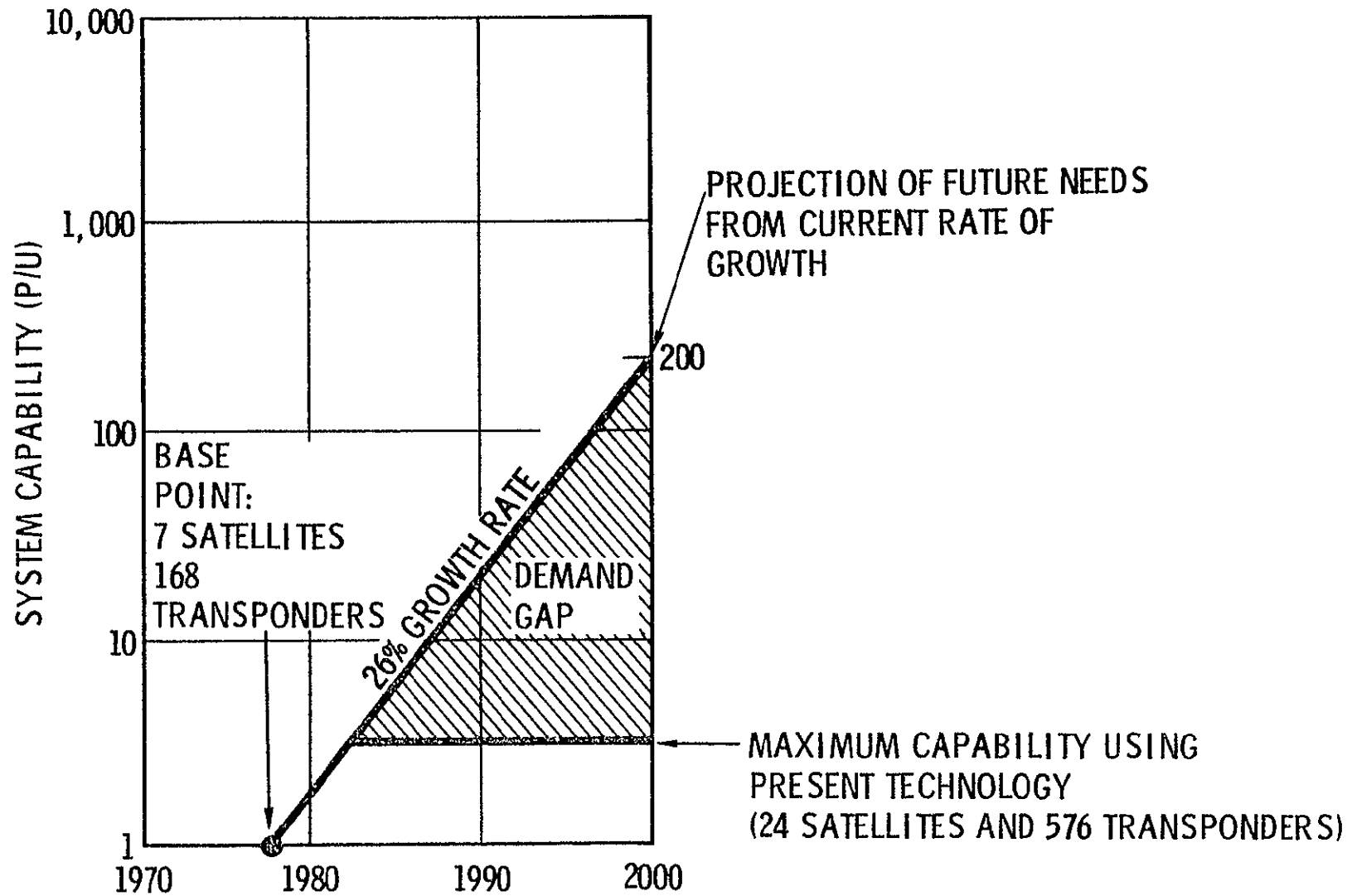


SOURCE: COMPUTERS AND TELECOMMUNICATIONS, OECD INFORMATION STUDIES 3, PARIS, 1973, AND STATISTICAL ABSTRACTS 1977 - U.S. DEPT OF COMMERCE

There are seven domestic communications satellites in service over the US. Two WESTAR satellites are operated as part of the Western Union network, three COMSTAR satellites (owned by COMSAT Corporation) are leased to the Bell System and GTE, and two RCA SATCOM satellites satisfy needs of other users. Each satellite provides 24 transponders working in the 6/4 gigahertz portion of the spectrum. These satellites are parked in about one-third of the total of 24 orbit positions spaced at 3° longitudinal intervals necessary to minimize interference and maintain elevation angles greater than 10° . The capacity of these seven satellites is plotted as the base point for the year 1977 on the facing chart.

Using the 26% annual growth projections, as cited in the previous discussion, the maximum capability using current technology, and the orbital parking space criteria, the 24 satellite positions would be required early in the next decade. By the year 2000, the projected need would exceed current capacity by some two orders of magnitude. As shown on the chart, the excess of need over present capacity as constrained by technology represents a significant demand gap.

THE DOMESTIC TELECOMMUNICATIONS DEMAND GAP



As stated earlier, there is an imbalance in the status quo with regard to the number of telephones in use and the distribution of the world population. A pictorial representation of this situation is shown on the facing chart.

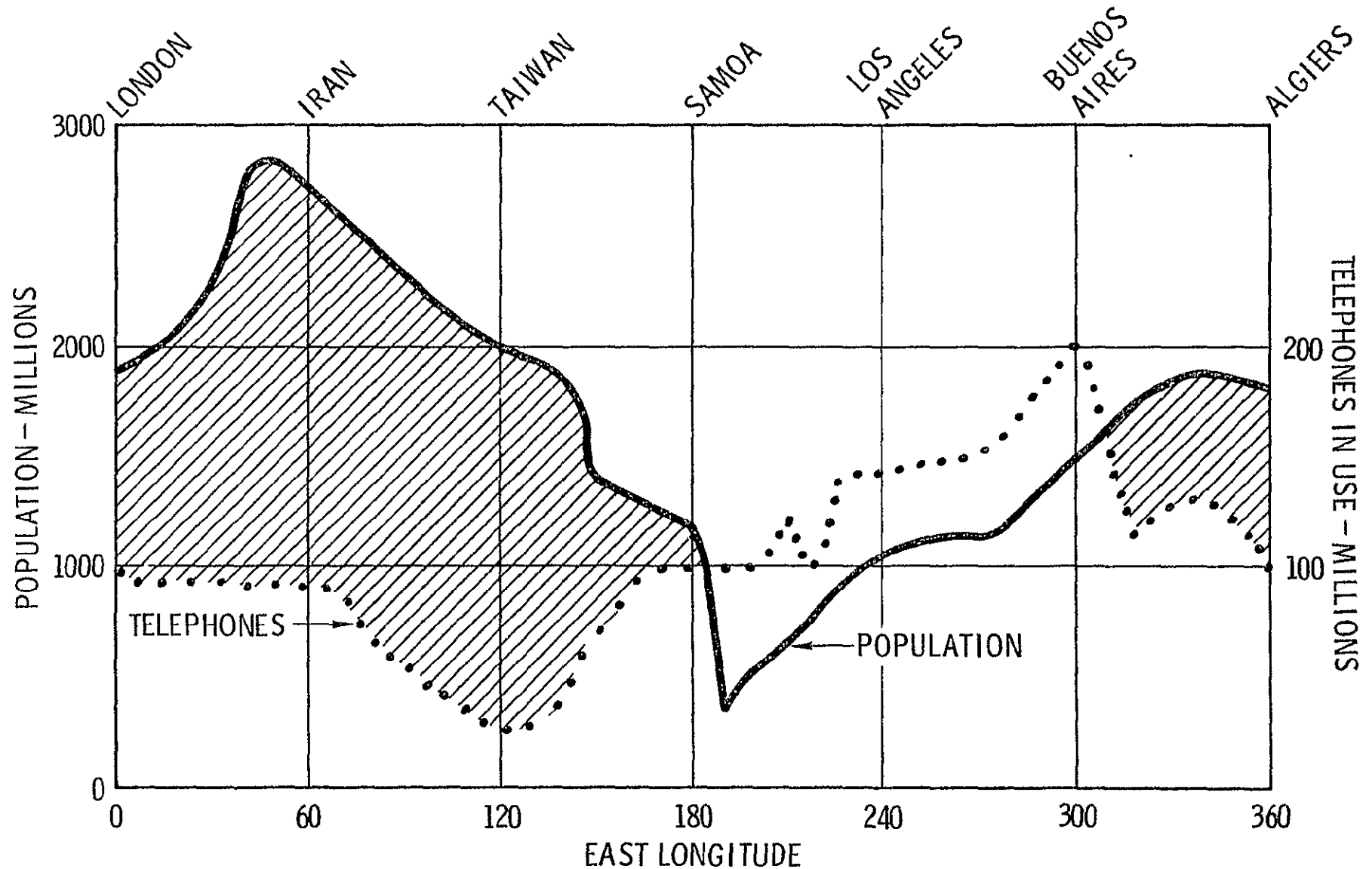
The solid curve on the chart represents the number of people that can be serviced from a given geosynchronous equatorial orbital position. For example, near 20° east longitude, where the nadir point would correspond roughly to Brazzaville, the capital of the Congo, some 2 billion people or one-half the present world's population, would be within the range of telecommunications satellite. The dotted curve, representing the number of telephones with that range, shows that fewer than 100 million out of a total of 350 million telephones worldwide could be serviced. A contrasting situation is shown at 200° east longitude near Jarvis Island in the central Pacific Ocean. Here, the same number of telephones are seen but the population in view has fallen below 500 million.

The shaded portion of the chart represents geographical regions where fewer telephones exist than the population would demand. A compounding factor in this imbalance is the projected population increase in these very regions. The opposite is true for the American continents. In these regions, largely because of the dominance of the US and Canada, telephones per capita far exceed worldwide averages.

Future adjustments to rectify the imbalance could be achieved more or less rapidly by relying more on satellite telecommunications. However, the satellite parking spots would lie largely within the 1° to 120° east longitude positions. Using standards for domestic US satellites, only 40 positions such would be available. The projected demand to meet an increase in population of some 1.6 billion by the year 2000 would require approximately 150 INTELSAT V class satellites. Current technological limitations add to the severity of this situation.

POPULATION AND TELEPHONES AS SEEN FROM GEOSTATIONARY ORBIT

35279



SOURCE: DOMESTIC SATELLITE: AN FCC GIANT STEP, R. S. MAGNANT, 1977

Telecommunications systems are directly related to population and standard of living, one measure of which is the gross national product. By the year 2000, the increase in telecommunications demand caused by both population increase and desire for improvements in the standard of living can be expected to grow 200-fold over current operational capacity.

The problem that must be solved is the imbalance between supply and demand - that is the demand is projected to grow rapidly on a worldwide basis due to the expanding and developing populations, and the growth potential to meet the demand is limited based upon current technology.

There are several solutions to the stated problem. Four typical ones are presented on the facing chart. The first solution, which could be characterized as a short-term approach, would merely attempt to maintain the status quo and thereby only address the projected increase on a basis of population growth alone. If current use rates remained constant, a mere 50% increase in population could easily be handled by current telecommunications systems technology. Unfortunately, this approach does not allow for any significant advances in service and capabilities.

The second postulated solution in realization of near-term socioeconomic consequences would satisfy future demands in a restricted manner. When new services need to be added, priority criteria would have to be satisfied. This approach would necessitate resolution of which criteria should be applied, a sociopolitical problem that could prove extremely difficult to negotiate and resolve. This approach would obviously promote a "favored user" philosophy.

A third approach would allow expansion of current systems to their maximum limit. Demand would be satisfied on a first-come first-served basis, assuming that economic and financial considerations could also be satisfied. Worldwide economic social and political considerations will influence and will certainly restrict the viability of this approach.

A fourth approach involves the previously discussed concept of complexity inversion. Advance technology would be directed toward long-term solutions of the burgeoning demands for communications services on a worldwide basis. This approach is the only one of the four which requires forward-looking action, and is the approach most likely to result in real growth for all nations of the world.

The discussions which follow will address the regulatory and technical factors involved in this fourth approach.

MEETING FUTURE NEEDS

THE PROBLEM

- BURGEONING DEMANDS OF EXPANDING AND DEVELOPING POPULATIONS ARE FORECASTED
- GROWTH POTENTIAL OF TRADITIONAL APPROACH TO TELECOMMUNICATIONS WILL NOT SATISFY DEMAND

POSSIBLE SOLUTIONS

- LIMIT GROWTH TO THE STATUS QUO
- RESTRICT NEW SERVICES TO MEET "BEST USE" CRITERIA
- EXPAND CURRENT SYSTEMS TO MAXIMUM LIMIT
- INITIATE COMPLEXITY INVERSION APPROACH

The next three charts present a comparative analysis of current telecommunications systems and future technological possibilities. The results suggest definite economic advantages of complexity inversion concepts over technology currently available.

FUTURE COMMUNICATIONS ALTERNATIVES - 1

FACTS

- CALLS/PHONE/DAY (US 1977 AVERAGE) = 3.26
- AVERAGE PLANT COST/TELEPHONE = \$650
- TELEPHONES WORLDWIDE (1974) = 350 MILLION
- TELEPHONES WORLDWIDE (2000) = 970 MILLION (4% GROWTH/ANNUUM)
- WITH NEW INNOVATIVE SERVICES AT 67% = 1.62 BILLION EQUIVALENT TELEPHONES BY YEAR 2000
- EQUIVALENT CALLS/DAY = 5.28 BILLION BY YEAR 2000
- CALLS/CIRCUIT - $24 \text{ HRS} \times 60 \text{ MIN} \div 3 \text{ MIN/CALL} = 480 \text{ CALLS/CIRCUIT}$
- REPLACEMENT PERIOD FOR TELECOMMUNICATIONS PLANT AND EQUIPMENT = 17 YR
- REQUIRED CIRCUITS - $5.28 \text{ BILLION} \div 480 = 11 \text{ MILLION BY YEAR 2000}$

FUTURE COMMUNICATIONS ALTERNATIVES - 2

CONVENTIONAL APPROACH

- INTELSAT V EQUIVALENT CIRCUITS = 12,000
- REQUIRED NUMBER OF SATELLITES – 11 MILLION $\div$ 12,000 = 917
- INTELSAT V INVESTMENT COST PER CIRCUIT YEAR = \$800
- TOTAL INVESTMENT COST – 11 MILLION $\times$ \$800 = \$8.8 BILLION/YR
- TELEPHONE COMPARABLE – 1.62 BILLION PHONES $\times$ \$650 $\div$ 17 = \$61.9 BILLION/YR

FUTURE COMMUNICATIONS ALTERNATIVES - 3

COMPLEXITY INVERSION APPROACH

- MULTIBEAM LENS SATELLITE SYSTEM (MBLS) - 4/6 GHz, 1000 BEAMS, 42 VOICE CHANNELS PER BEAM = 42,000 CIRCUITS/MBLS

- NUMBER OF MBLS REQUIRED - $11 \text{ MILLION} \div 42,000 = 262$

FOR 10-YEAR SERVICE LIFE INVESTMENT COST - $\$280 \text{ MILLION} \times 262 \div 10$
 = $\$7.34 \text{ BILLION/YR}$

- INVESTMENT OF GROUND - $\$10 \times 1.62 \text{ BILLION} = \16.2 BILLION

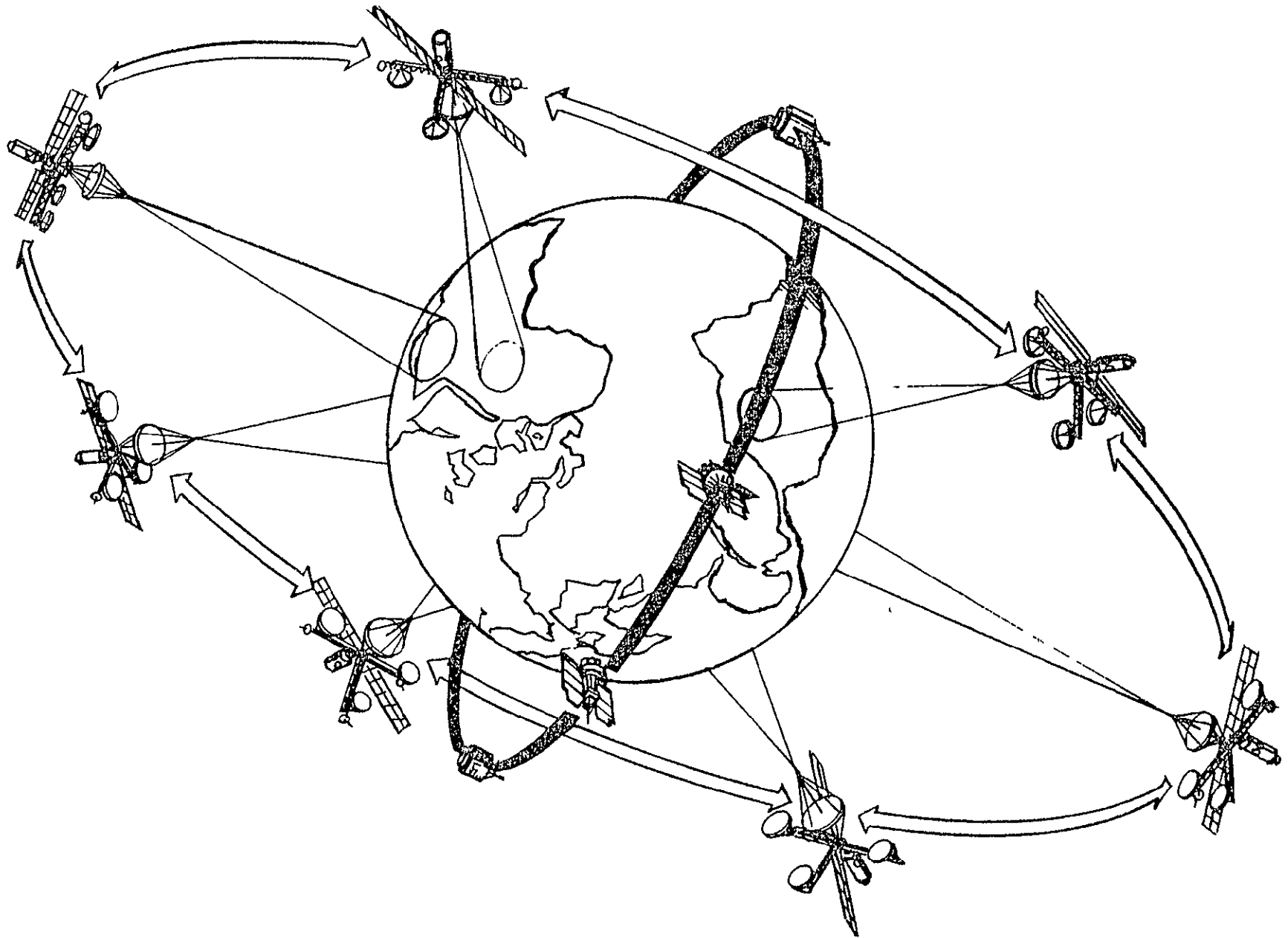
- FOR ONE-YEAR SERVICE LIFE TOTAL INVESTMENT = $\$23.5 \text{ BILLION/YR}$

- GROSS ECONOMIC ADVANTAGE - $\$61.9 \text{ BILLION} \div \$23.5 \text{ BILLION} = 263\%$

The complexity inversion concept appears to provide an economically attractive approach for closing the demand gap and satisfying future service needs.

Support of research and technology development to validate the concept appears warranted.

INTERACTIVE INFORMATION SERVICE SYSTEMS



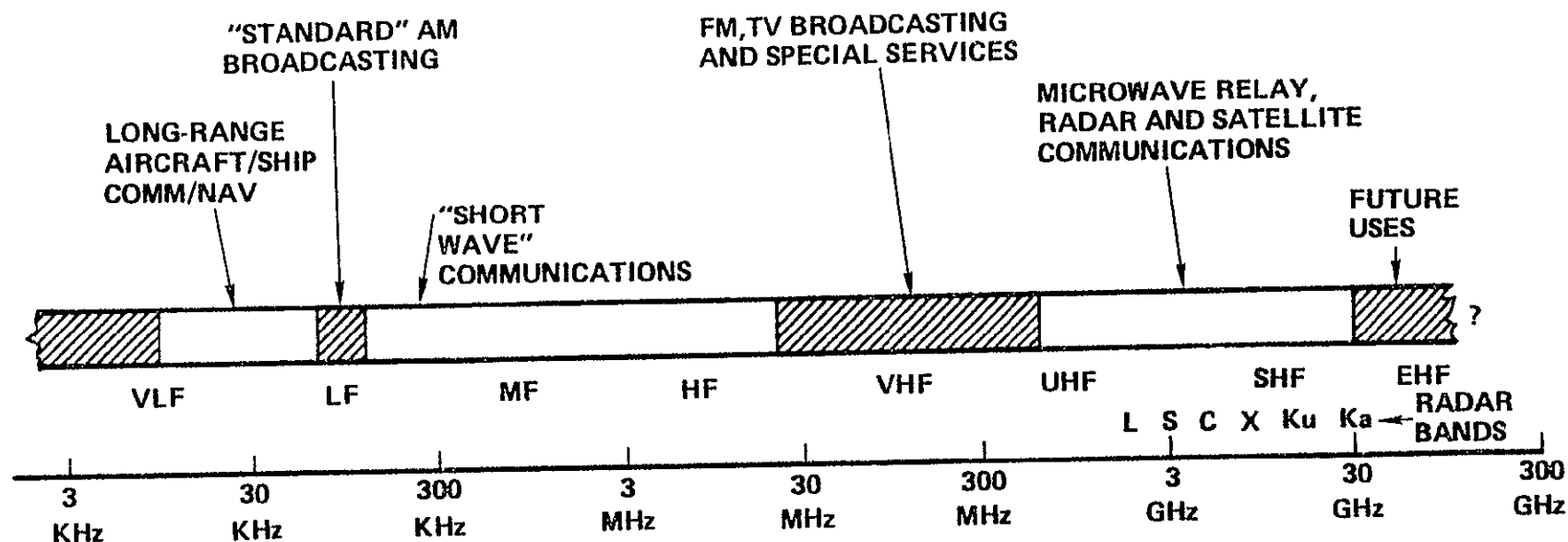
REGULATORY CONSTRAINTS AND PHYSICAL LIMITATIONS

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The electromagnetic spectrum is divided into a number of regions such as the communications band, infrared, ultraviolet, etc. The communications band, in turn, comprises the standard radio broadcast, television, radio astronomy, and radar bands with frequencies controlled and assigned within the US by the Federal Communications Commission (FCC) and internationally by the International Telecommunications Union (ITU). The communications band is also subdivided into specific frequency regions such as very low frequency (VLF), low frequency (LF), medium frequency (MF), etc. Within this band, specific ones are allocated for the various users, i. e., military, broadcast satellite services, fixed satellite services, etc. In some cases, a band is allocated to more than one user type, in which case it is classified as "shared."

The manner in which requests for portions of the frequency spectrum should be submitted have been specified in the rules and regulations published by the FCC. These rules also specify the constraints with which space and ground systems must comply.

FREQUENCY ALLOCATION OF THE RADIO SPECTRUM



PUBLIC AND PRIVATE USE
OF RADIO SPECTRUM
REGULATED AND CONTROLLED
BY FCC IN USA (1934) AND
INTERNATIONALLY BY ITU (1865)

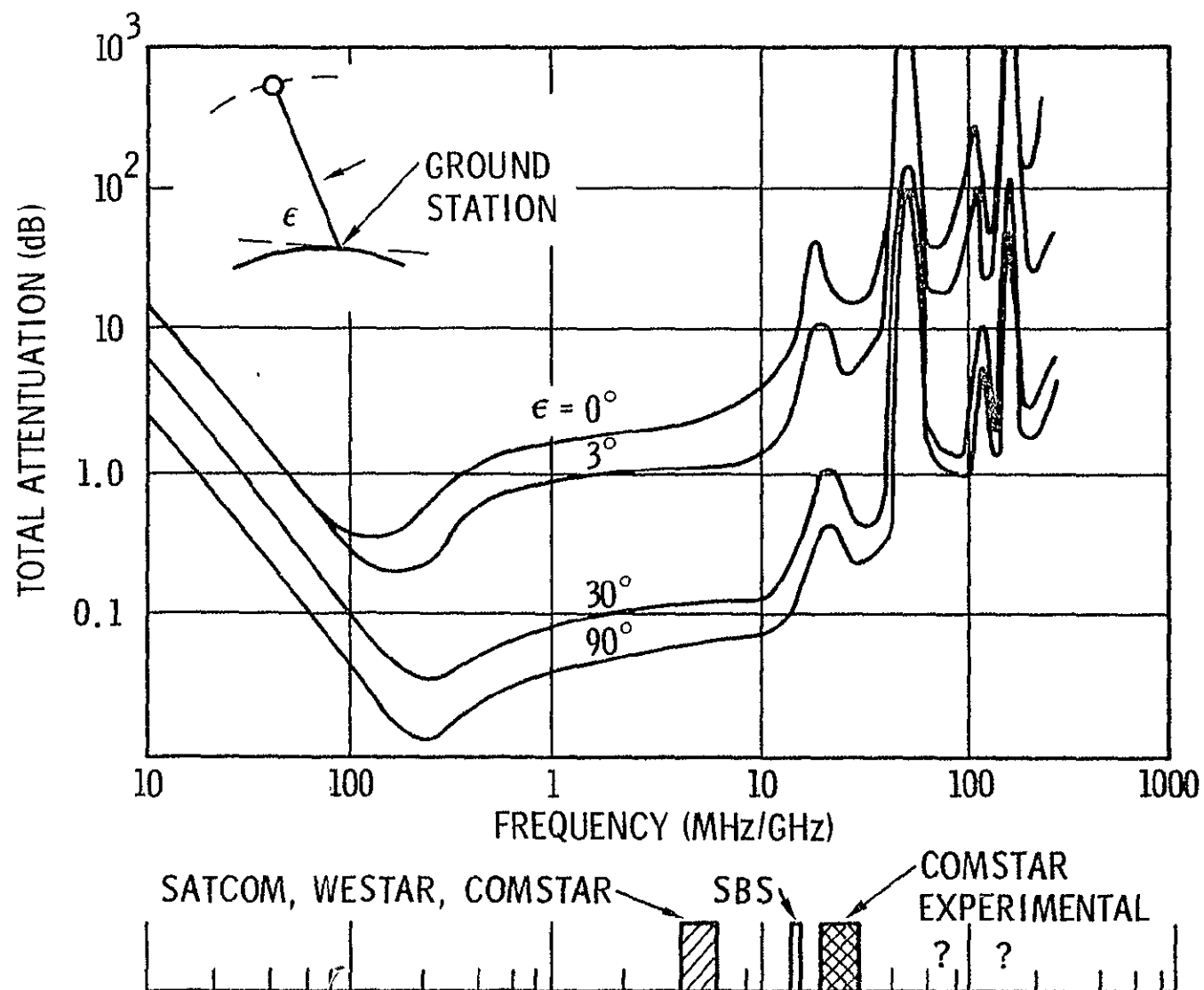
RADIO
ASTRONOMY
"WINDOW"

Atmospheric propagation constraints in terms of signal attenuation and noise due to gas and water absorption and scattering above 1 GHz and galactic noise below 1 GHz are illustrated on the facing chart. In viewing these effects, it readily becomes apparent why the centimeter band has become congested between 2 and 8 GHz. It may also be observed that the newer satellites such as Comstar, and such experimental satellites as ATS-6, LES-8 and -9, OTS, and ECS are penetrating frequency regimes to 40 GHz by using "windows" in the spectrum, improving the self-generated noise performance of new receivers and by increases in equivalent isotropic radiated power (EIRP); the latter by increases in amplifier power output and the use of narrow-beam antennas.

Since wavelengths become smaller as frequencies increase, the trend toward higher frequencies has allowed narrow beams to be produced by antennas which are comparatively small, lightweight, and inexpensive. Once research has solved the hardware technology problems, bandwidths adequate for all conceivable future needs will become available.

SPACE-TO-GROUND ATTENUATION CHARACTERISTICS

35265



International Radio Regulations become law upon adoption by representatives of the ITU member nations during General World Administrative Radio Conferences. In preparation for the conferences, the FCC publishes Notices of Inquiry (NOI) which request comments on new or revised regulations. For example, a third NOI released December 6, 1976, solicited comments on a proposed International Frequency Allocation Table. The commission then considered the various positions taken by respondees and established a position for the conference.

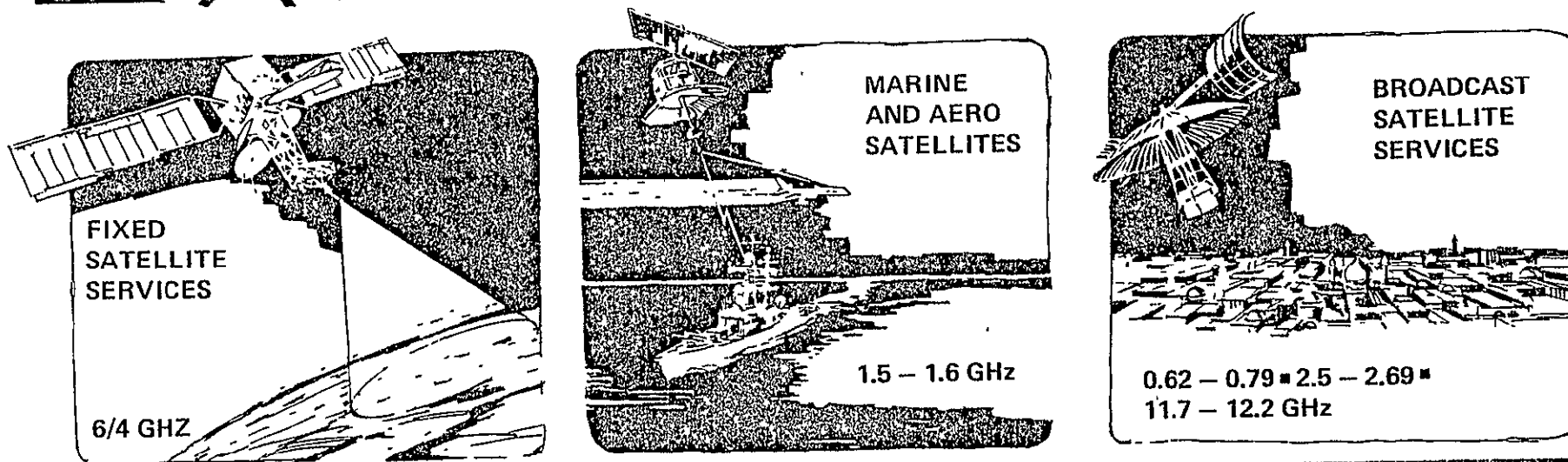
Allocations affecting telecommunications which have been previously adopted for Fixed Satellite Services, Marine and Aero Satellites, and Broadcast Satellites are shown in Charts 36559 and 36560. Charts 35797A and 35798 expand on these allocations for communications satellites, the rules governing emission limitations, power limits, and the flux density with which systems must comply. In addition, considerable proof must be provided that interference with existing systems will not occur before the FCC approves any new systems or programs.

The ITU has also established committees and working groups to analyze the performance and characteristics of new systems and make recommendations regarding their technical characteristics. Upon approval of the study results, they are used as guidelines by designers of equipment for intercontinental networks to ensure system compatibility.



REGULATORY CONSTRAINTS

- RF SPECTRUM ALLOCATION MADE BY INTERNATIONAL TELECOMMUNICATIONS UNION (ITU) OF UNITED NATIONS



- MAXIMUM FLUX DENSITY IMPINGING ON SURFACE OF EARTH RESTRICTED TO -130 dBW/M^2

■ OTHER CONSTRAINED QUANTITIES

- INTERCONNECTION OF TIME MULTIPLEXED, VIDEO AND TELEPHONE SYSTEMS
- RF CHANNEL ARRANGEMENTS
- PERMISSABLE NOISE AND INTERFERENCE
- PRE-EMPHASIS DEVIATION AND MODULATION CHARACTERISTICS
- SERVICE CHANNELS, PILOTS AND SWITCHING

FREQUENCY BANDS FOR SATELLITE COMMUNICATIONS

36559

(FCC DOCKET NO. 19547 ADOPTED 7/18/72)

AERONAUTICAL AND MARITIME - SATELLITE SERVICES:

- 1,535 TO 1,542.5 MHz, MARITIME
- 1,542.5 TO 1,543.5 MHz, AERONAUTICAL/MARITIME
- 1,543.5 TO 1,558.5 MHz, AERONAUTICAL
- 4.2 TO 4.4 GHz AERONAUTICAL
- 5.0 TO 5.25 GHz, AERONAUTICAL
- 15.4 TO 15.7 GHz, AERONAUTICAL
- 157 MHz, DISTRESS FREQUENCIES
- 43 TO 48 GHz, AERONAUTICAL MOBILE SATELLITE
- 66 TO 71 GHz, NAVIGATION SATELLITE

EARTH RESOURCES SATELLITE SERVICES:

- 401 TO 403 MHz UPLINK
- 460 TO 470 MHz DOWNLINK
- 1.67 TO 1.7 GHz DOWNLINK
- 2.025 TO 2.12 GHz UPLINK
- 8.025 TO 8.4 GHz DOWNLINK
- 21.2 TO 22.0 GHz DOWNLINK

SPACE RESEARCH SERVICE:

- 2.2 TO 2.3 GHz DOWNLINK
- 8.4 TO 8.5 GHz
- 14.4 TO 15.35 GHz

FREQUENCY BANDS FOR SATELLITE COMMUNICATIONS

(FCC DOCKET NO. 19547 ADOPTED 7/18/72)

BROADCAST SATELLITE SERVICE (DIRECT RECEPTION BY GENERAL PUBLIC):

- 0.620 TO 0.790 GHz
- 2.50 TO 2.69 GHz DOMESTIC AND REGIONAL
- 11.7 TO 12.2 GHz
- 41.0 TO 43.0 GHz
- 84.0 TO 86.0 GHz

FIXED-SATELLITE SERVICES (DATA, TELEPHONE, TV DISTRIBUTION):

- 2.5 TO 2.535 GHz COMMON CARRIER
- 3.5 TO 4.2 GHz
- 6.625 TO 7.125 GHz DOMESTIC
- 10.75 TO 11.2 GHz INTERNATIONAL ONLY
- 11.45 TO 11.7 GHz INTERNATIONAL ONLY

- 11.7 TO 12.2 GHz DOMESTIC ONLY
- 17.7 TO 19.7 GHz
- 19.7 TO 21.2 GHz
- 40.0 TO 41.0 GHz
- 102.0 TO 105.0 GHz
- 150.0 TO 152.0 GHz
- 220.0 TO 230.0 GHz
- 265.0 TO 2,750 GHz

INTER-SATELLITE COMMUNICATIONS SERVICE:

- 54.8 TO 58.2 GHz
- 59 TO 64 GHz
- 105 TO 130 GHz
- 170 TO 182 GHz
- 185 TO 190 GHz

This figure and the succeeding one (Chart 35798) contain a summary of communications satellite rules and regulations published in March, 1974, by the FCC in Part 25, Satellite Communications, by the authority contained in Section 201(c) (11) of the Communications Satellite Act of 1962. They are included here as representative of the rules and regulations governing all telecommunications. Under Technical Standards the assigned frequencies, frequency tolerances, and emissive limitations are defined. The satellite-to-earth band may also be used for communications satellite space stations operating in the same band, while the earth-to-satellite band may also be used for telecommand, indicating the necessary degree of sharing of the spectral resource. The choice of sites and frequencies for earth stations is controlled to minimize the possibility of harmful interference between the sharing services.

COMMUNICATIONS SATELLITES RULES AND REGULATIONS - MARCH 1974

35797A

- SERVICE

SATELLITE TO EARTH
EARTH TO SATELLITE
TELECOMMAND

TELEMETERING

TRACKING

- CARRIER FREQUENCY TOLERANCE
(EARTH STATION)

- CARRIER FREQUENCY TOLERANCE
(SPACE STATION)

- EMISSION LIMITATIONS (4-KHz BAND)
ATTENUATION

FREQUENCIES

3700 TO 4200 MHz

5925 TO 6425 MHz

148.25 MHz, 154.2 MHz

(30 KHz CHANNEL BANDWIDTH)

450 MHz (0.5 MHz BANDWIDTH), 1427 TO 1429 MHz

136 TO 137 MHz, 137 TO 138 MHz, 400.05 TO 401 MHz,

401 TO 402 MHz, 1525 TO 1540 MHz

136 TO 137 MHz, 137 TO 138 MHz, 400.05 TO 401 MHz,

1525 TO 1540 MHz

0.001% OF REFERENCE FREQUENCY

0.002% OF REFERENCE FREQUENCY

25 dB - CENTER FREQUENCY REMOVED FROM
ASSIGNED FREQUENCY BY 50% UP TO 100%
OF AUTHORIZED BANDWIDTH

35 dB - CENTER FREQUENCY REMOVED FROM
ASSIGNED FREQUENCY BY 100% UP TO 250%
OF AUTHORIZED BANDWIDTH

43 dB - CENTER FREQUENCY WHICH IS REMOVED
BY MORE THAN $+10 \log_{10}$ TRANSMITTER
POWER UP TO 250% OF AUTHORIZED BANDWIDTH

Power limits for the earth station are also rigidly controlled in the horizontal direction as are minimum antenna angles of elevation to further reduce the possibility of interstation interference. In a like manner, power flux density at the earth's surface produced by emission from a communications satellite is constrained for all angles of arrival. Ground station antenna performance is also controlled. Finally, to ensure that the requisite levels are achieved, maximum permissible interference power and percentage of the time during which levels may exceed the maximum level are specified.

COMMUNICATIONS SATELLITES RULES AND REGULATIONS - MARCH 1974 (CONT)

• POWER LIMITS

(WITHIN BAND 5925 TO 6425 MHz)

MAX 45 dB IN ANY 4-KHz BAND IN HORIZONTAL PLANE

(WITHIN BAND 7900 TO 8400 MHz)

MAX 55 dB IN 4-KHz BAND IN HORIZONTAL PLANE
EXCEPT 65 dB UPON SHOWING NEED FOR
GREATER POWER

• ANGLE OF ELEVATION - MINIMUM

5° FROM HORIZONTAL PLANE ALTHOUGH
MINIMUM OF 3° WILL BE CONSIDERED

(5925 TO 6425 MHz)

• POWER FLUX DENSITY

(WIDE DEVIATION FREQUENCY OR
PHASE MODULATION)

-130 dBW/M²

(OTHER MODULATION TYPES)

-149 dBW/M² IN ANY 4-KHz BAND

-152 dBW/M² IN ANY 4-KHz BAND

• ANTENNA PERFORMANCE

(OUTSIDE MAIN BEAM)

32 TO 25 LOG₁₀ dBi 1° ≤ 0 ≤ 48°

-10 dBi 48° < 0 ≤ 180°

MAXIMUM PERMISSIBLE INTERFERENCE
POWER

LENGTHY (SEE RULES AND REGULATIONS; PART 25)

Broadcast satellite service (BSS) for individuals and communities is expected to rapidly expand in the 1980's, providing services such as direct video reception, educational programming, medical data interchange, etc. The need for additional Public Service Satellite System spectrum allocations has been expressed by the World Administration Radio Conference (WARC) 1979 Service Working Groups on Satellite Broadcasting. However, proposals for new allocations have generally been denied.

This figure illustrates the present frequency allocations and the original channel needs forecast developed by the groups. Since the bandwidth allocations were insufficient at the lower frequencies to meet the forecast needs (desired due to equipment availability), additional allocations were requested in the bands shown. These were denied as was a request to move to the 12.2-to-12.56 GHz band due to a decrease in the projected capacity of the 11.7-to-12.2 GHz band, based upon system characteristics adopted by the WARC-BS. The 19.7-to-21.2 GHz allocation request was also denied.

The original WARC-79 needs forecast has now been reduced but the 11.7-to-12.2 GHz band is still incapable of providing the requisite channel quantity. The higher-frequency band allocations would provide this capacity, but their technical characteristics are relatively unknown at present, and equipment providing adequate performance at reasonable cost is not generally available.

BROADCAST SATELLITE FREQUENCY ALLOCATIONS STATUS

35799

- BSS FREQUENCY ALLOCATIONS
(EXISTING) (REGION 2) 670 TO 790 MHz, 2500 TO 2690 MHz, 11.7 TO 12.2 GHz,
41 TO 43 GHz, 84 TO 86 GHz
- ORIGINAL NEEDS FORECAST 1240 TO 1307 EQUIVALENT COMMUNITY RECEPTION TV
CHANNELS (BC)
205 INDIVIDUAL RECEPTION CHANNELS (BI)
BI SPECTRUM ALLOCATION = 5.76 BC CHANNELS
- BSS FREQUENCY ALLOCATIONS 420 TO 450 MHz (6 MHz TOTAL); MOVED TO 470 TO
805 MHz
2300 TO 2500 MHz; DENIED
3400 TO 3700 MHz; DENIED
12.2 TO 12.5 GHz; DENIED
19.7 TO 21.2 GHz; DENIED
- REVISED NEEDS FORECAST 149 COMMUNITY CHANNELS
PER TIME ZONE 64 INDIVIDUAL RECEPTION CHANNELS
- CAPABILITY IN 11.7 TO 12.2 GHz BAND 125 COMMUNITY CHANNELS
OR 48 INDIVIDUAL RECEPTION CHANNELS

ALLOCATION TO THE BSS IN BAND 19.7 TO 21.2 GHz DENIED IN PARAGRAPH 118
OF THE THIRD NOTICE AND NOT DISCUSSED IN FIFTH

OTHER ALLOCATED BANDS 41 TO 43 GHz AND 84 TO 86 GHz HAVE UNKNOWN TECHNICAL
CHARACTERISTICS WHICH MAY NOT BE SATISFACTORY FOR SOME SATELLITE
BROADCASTING APPLICATIONS

The 1977 WARC on BSS decided that a regional conference should be held no later than 1982 for the purpose of carrying out detailed BSS planning. This figure depicts some of the characteristics of the system concept presently envisioned. The characteristics are generally consistent with the Public Service Communications Satellite System (reference Draft Report, Public Service Communications Satellite System Review and Experiment Definition Workshop, Goddard Space Flight Center, March 29, 1977). The Video Program Originating Station would transmit 200 watts through a 3-meter dish on the uplink, while video receive terminals would use 1.8-meter dishes. The spacecraft would employ a regional antenna providing 35.9-dB gain and EIRP of 53.9 dB. The 1.8-meter dishes have been selected as the smallest size suitable for community broadcast satellite service (BSS-C) and a 1-meter size has been selected for individual reception (BSS-I).

MODEL OF BSS AT 11.7 TO 12.2 GHz

ASSUMPTIONS:

1. CONTIGUOUS 48 STATES ARE SERVED BY A NUMBER OF BROADCASTING SATELLITES OF SAME KIND
2. TECHNICAL PARAMETERS USED BY 1977 WARC-BS ARE USED
3. ANTENNA DIAMETERS FOR COMMUNITY RECEPTION EARTH STATIONS ARE 1.8M, 2.5M, 3.5M
4. NINE SERVICE AREAS ARE ASSUMED (TWO EACH FOR PACIFIC, MOUNTAIN AND CENTRAL TIME ZONES, THREE FOR EASTERN TIME ZONE)
5. US SATELLITES (EASTERN ARC) FROM 5° TO 85° W LONGITUDE; (WESTERN ARC) 140° TO 170° W LONGITUDE
6. US SATELLITES ARE OF COMMUNITY TYPE (BSS-C); FOREIGN SATELLITES ARE OF INDIVIDUAL TYPE (BSS-I)
7. ANTENNA DIAMETERS FOR INDIVIDUAL TYPES ARE 1M AND FOR COMMUNITY TYPES ARE 1.8M
8. SATELLITE AND EARTH STATION ANTENNAS CONFORM TO PATTERNS ADOPTED BY 1977 WARC-BS
9. PROTECTION RATIOS ARE 32 dB (BSS-C) AND 35 dB (BSS-I)

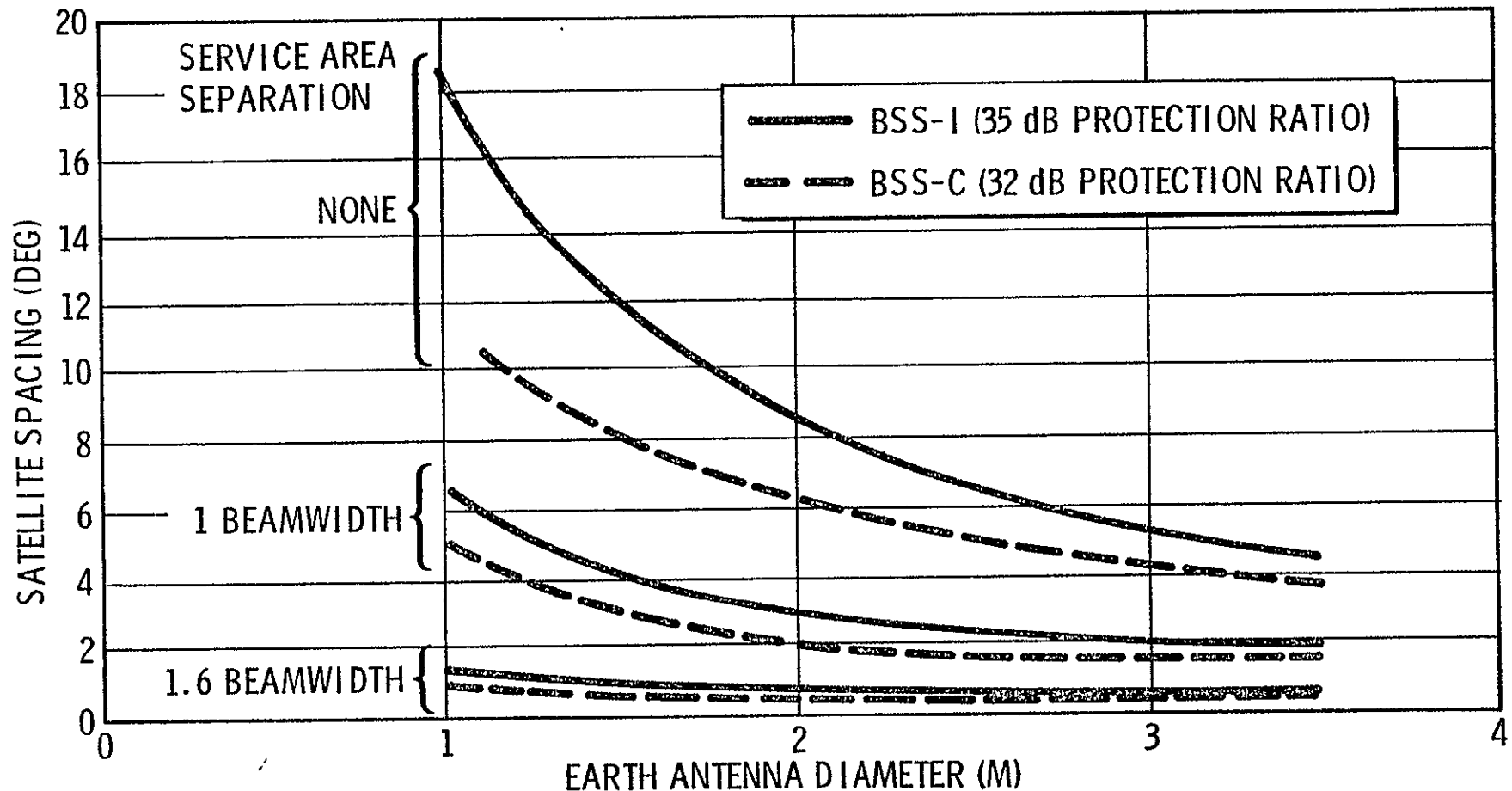
Maximum use of the 11.7-to-12.2 GHz band can be made if frequencies are reused. Discrimination can be achieved by the use of orthogonal polarization or by the receiver antenna when sufficient spacing exists between satellites.

This figure illustrates the required satellite spacing as a function of the ground antenna size for various service area separations. The difference between the BSS-I and BSS-C is that the equivalent isotropic radiated power (EIRP) is lower by 6 or 10 dB and the protection ratio required is, therefore, also lower. For the antenna patterns assumed, the 35- and 32-dB protection ratios are reached at 9.55 beamwidths and 7.24 beamwidths, respectively.

It is clear that as antenna diameters become larger and beamwidths smaller, satellite spacing requirements are reduced. It is also clear that if frequency reuse is limited to noncontiguous service areas, satellites can be spaced quite closely. It may also be inferred that discrimination requires reasonable pointing accuracy of ground receiving antennas.

SPACING REQUIRED BETWEEN BROADCAST SATELLITES USING SAME FREQUENCY BANDS*

35801A



*DATA OBTAINED FROM COMMENTS OF WARC-79 SERVICE WORKING GROUP
ON SATELLITE BROADCASTING, 8/24/77

Based upon a review of current documents, it appears that considerable development is required and is, indeed, being performed to provide equipment at reasonable cost at higher frequencies, since congestion and competition exist for frequencies in the lower part of the spectrum.

Interference between systems has been found to be a major concern, and strict constraints have been placed upon site location, antenna patterns, and the allowable power density which can be transmitted on earth and in orbit. Spot beams and pattern shaping are presently being used to reduce interference and allow frequency reuse, thereby helping to reduce congestion.

For the future, the trend is toward use of higher parts of the radio spectrum (wherever windows exist) and to increase the complexity of on-orbit systems. The latter allows the use of simpler or smaller ground equipment and produces a larger number of potential telecommunications users.

C-2

35802

FACTORS IN SYSTEM DEVELOPMENT

- CONGESTION/COMPETITION EXISTS FOR FREQUENCIES IN LOWER BANDS
- INTERFERENCE CONCERNS LIMIT ALLOWABLE POWER DENSITY ON EARTH AND IN ORBIT
- USE OF SPOT BEAMS REDUCES CONGESTION AND ALLOWS FREQUENCY SHARING
- USE OF HIGHER FREQUENCY BANDS LIMITED BY EQUIPMENT DEVELOPMENT STATUS AND COST
- TREND IS TO INCREASE SPACE SYSTEM COMPLEXITY AND REDUCE GROUND SYSTEM COMPLEXITY AND COST

CHARACTERISTICS OF FUTURE SYSTEMS

INFORMATION PAGE BEANK NOT FILMED

Telecommunications functions and concept characteristics which may be typical spacecraft of the 1990-to-2000 time period are shown. Antenna diameters, power, number of beams, etc., are generally large enough to require on-orbit assembly, although sizes are tied to assumed frequency bands and could become much smaller should higher operational frequencies be selected.

Of particular interest is the number of beams produced by each satellite and the potential number of voice channels involved. They result in rather complex on-orbit switching requirements and satellite sophistication as compared to the typical "bent pipe" operation of current systems.

MBL-ORIENTED AEROSPACE INITIATIVES

SYSTEM CHARACTERISTICS	PERSONAL COMMUNICATIONS	VOTING/POLLING WRIST SET	URBAN/POLICE WRIST RADIO	DISASTER COMMUNICATIONS	BURGLAR ALARM/ INTRUSION DETECTION	VEHICULAR SPEED CONTROL	ENERGY MONITOR	VEHICLE/PACKAGE DETECTOR	ADVANCED TV BROADCAST	3D/HOLOGRAPHIC TELECOMMUNICATIONS	ELECTRONIC MAIL TRANSMISSION	NATIONAL INFORMATION SERVICE	NUCLEAR FUEL DETECTOR (2)	DIPLOMATIC/U.N. HOTLINES
MBL DIA – (M)	61	45	61	61	61	61	45	45	25	25	61	61	12	1.5
NO. OF BEAMS	25	116	250	250	500	100	116	116	250	100	1000	1000	116	200
RAW POWER – (KW)	21	30	75	75	1	430	23	23	150	220	15	15	0.3	1
SPACECRAFT WGT/ (KG)	7300	5900	8200	8200	7300	8600	4600	4600	6400	6800	9100	9100	1400	1400
CONSTELLATION SIZE (NO.)	1	1	1	1	1	1	1	2	1	1	1	1	4	3
BEAMWIDTH – (°)	0.18	0.53	0.35	0.35	0.12	0.12	0.4	0.4	0.26	0.26	0.12	0.12	0.4	1
(1) PERSONS AFFECTED – (M) (YEAR 2000)	262	185	200	262	200	200	262	262	262	50	262	262	262	6182
(1) MESSAGE RATE – OWC	250K	1500	2500	2500	500	100K	10K	100	500K	2.4M	50K	1X10 ⁸	10K	400

OWC = ONE WAY VOICE CHANNELS

(1) = DERIVED CHARACTERISTICS

(2) = NOT IN GEO

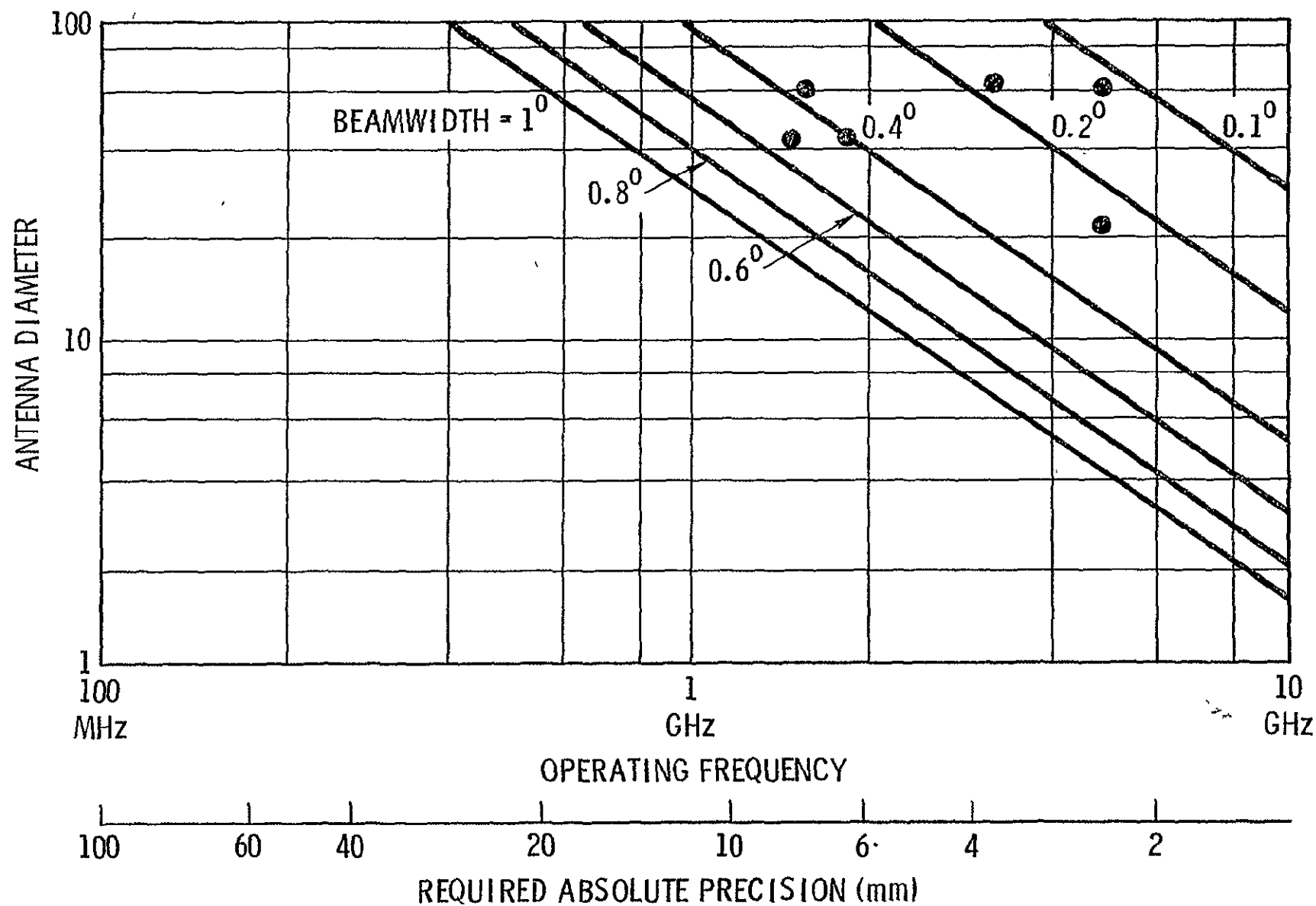
To achieve the narrow beamwidths and large gains provided by the MBL system characteristics of Chart 35258, antenna surface accuracy must be maintained to very close tolerances. If we use the Ruze gain formula (which only holds for parabolic antennas and whose derivation is based upon many assumptions which may not be applicable) and limit gain degradation to 1 dB, the surface tolerance which must be achieved is $1/26.2$ of the wavelength. In the JPL report, A Large Aperture Space Antenna, dated March 29, 1977, the operating frequency was set when the RMS surface tolerances equaled $1/32$ of the wavelength. The degree to which these would be applicable to an MBL are unknown but should provide a reasonable rule of thumb.

The facing figure illustrates the beamwidths provided by antennas of various diameters and the specific precision which must be maintained for the MBL concepts.

COMMUNICATIONS SATELLITE ANTENNA REQUIREMENTS

35277

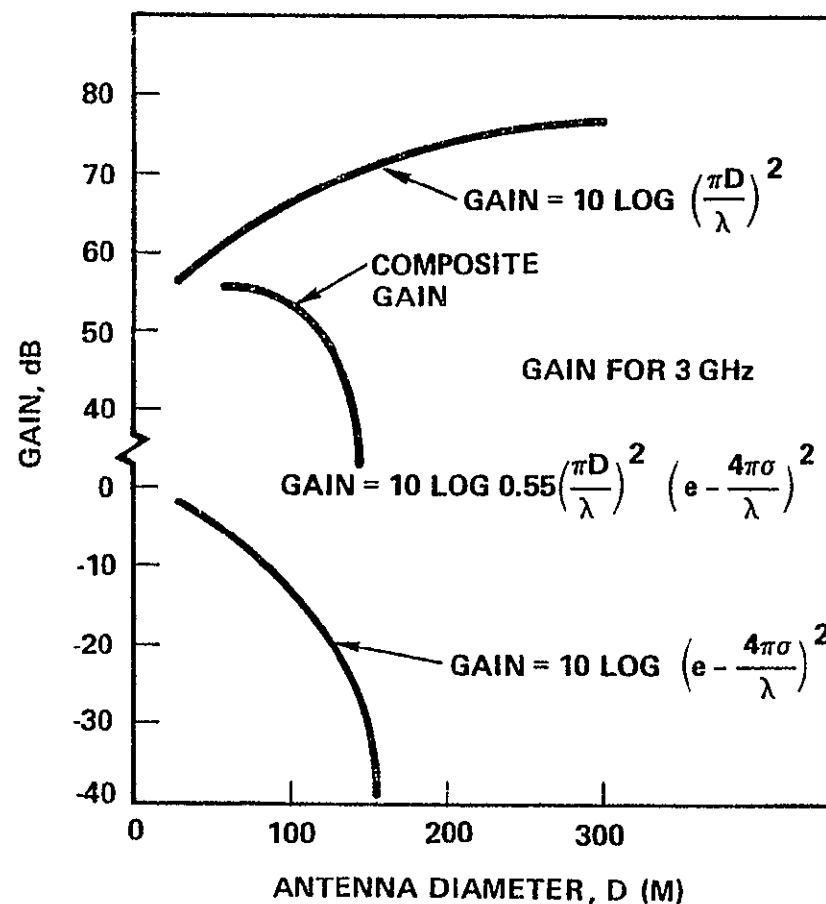
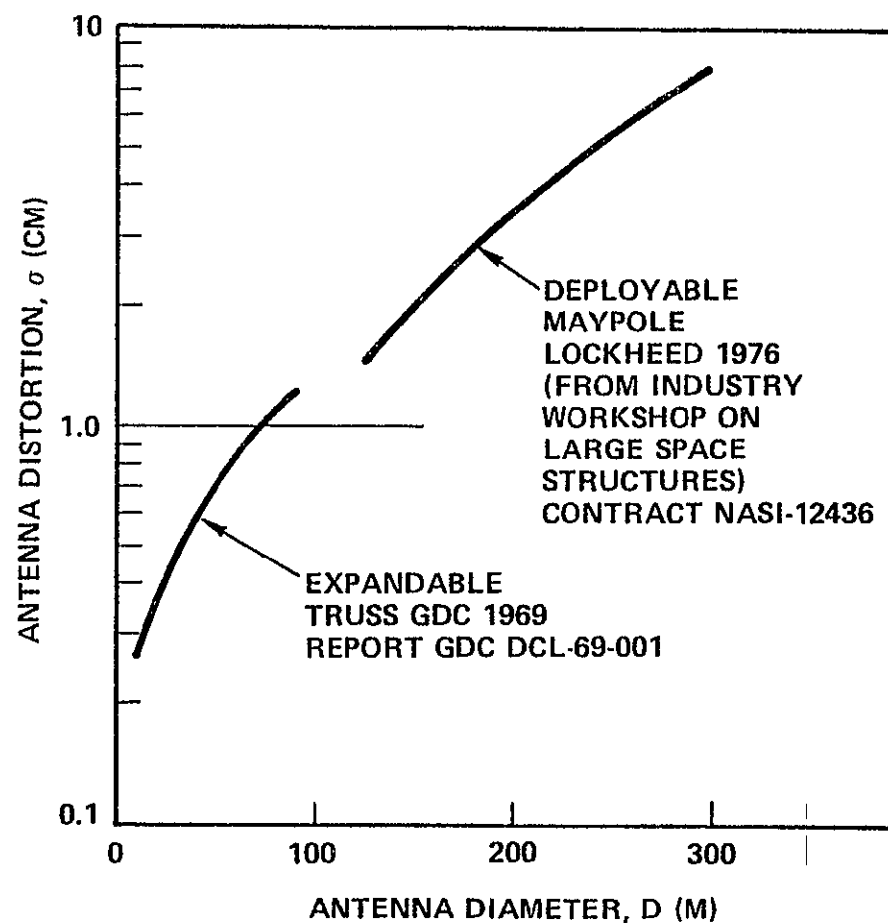
MOD



The figure on the left of the facing chart indicates the achievable antenna distortion as a function of antenna diameter postulated by two sources for parabolic deployed antennas. The levels shown include worst-case manufacturing and thermal distortion induced on orbit, the latter being the major offender. In comparison to ground antennas, which appear to have an exponential distortion characteristics as a function of diameter (which may be attributed to gravity effects), the levels for larger diameters are significantly lower.

The figure on the right illustrates the gain that may be achieved if only the first term of the gain equation is used, the effective reduction in gain when the loss term is taken into account, and the composite gain at a frequency of 3 GHz. It is seen that no advantage is provided by the larger antenna at the achievable levels of distortion. As a result, it has been concluded either assembly on orbit, operation at lower frequencies (or use of a smaller antenna area for higher frequencies where multiple feeds are employed), or small antennas should be employed at frequencies much above 1 GHz. In general, the maximum frequency of operation may be determined by use of the equation $f_{\max} \text{ (GHz)} = 0.94/\sigma \text{ (in.)}$.

IMPACT OF DISTORTION ON GAIN OF DEPLOYED ANTENNAS



During the recently completed Space Station Systems Analysis Study (Contract NAS9-14958), Ford Aerospace, in conjunction with MDAC, developed a concept for a multibeam lens antenna for electronic transmission and reception of mail. Its characteristics were as follows: Operating at X_o-band, it provided 1000 beams, had a total bandwidth of 10^5 MHz, a gain/temperature (G/T) ratio of 30 dB/K, and an equivalent power of 94.7 dBW. For sizing purposes, each beam was assumed to encompass 100 post offices thereby allowing the satellite to service 100,000 post offices. Each post office would transmit data at a 1 Mbps rate.

Among the difficult specifications to meet was the need to ensure that sidelobe interference would be down a minimum of 30 dB. Also, the ability to switch channels between 1000 x 1000 ports in less than a second was considered to present a challenge.

27m MULTIBEAM LENS SATELLITE

ANTENNA TYPE: LENS

DIAMETER: 27M

FREQUENCY: X-BAND (8 GHz)

NUMBER OF BEAMS: 1000

FREQUENCY REUSE: 100 TIMES

BEAMWIDTH: 0.09 DEG (HALF POWER)

BEAM SPACING: 0.1 DEG CENTERS

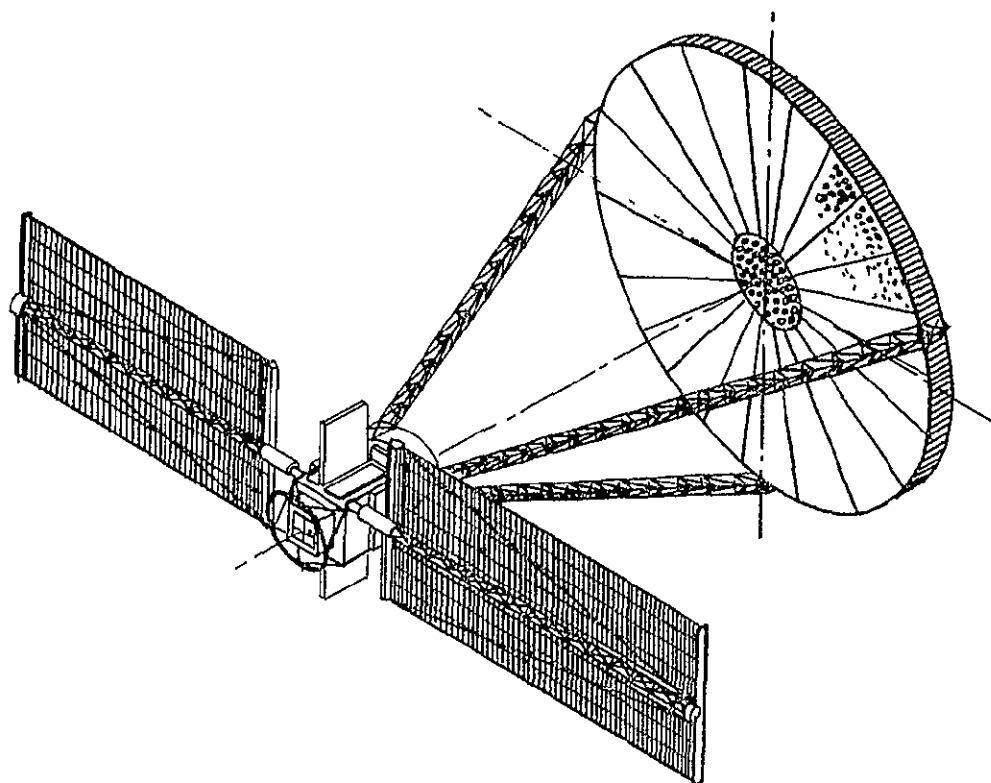
BEAM-TO-BEAM ISOLATION: 25 dB

SIDELOBES: <30 dB

GAIN (EACH BEAM): 60 dB

RF POWER: 5 TO 10 WATTS/BEAM

DC POWER REQUIRED: 16.75 KW



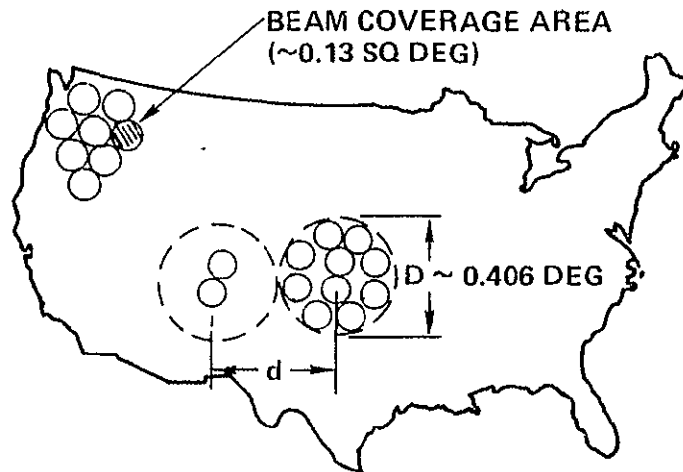
An initial analysis was performed on the multiple-beam lens concept to ascertain the diameter of the lens as a function of maximizing the isolation between beams. The concept itself consists of a 1000-beam TEM lens, each beam covering a spot of 0.1 of a degree of the CONUS. A frequency coverage set is 10 contiguous beams, each with a different frequency allocations, as illustrated in Section A. Therefore, 100 such sets would cover the CONUS, and 100-beam frequency reuses would be required for each frequency allocation.

Section B illustrates the relative gain of all other like frequency beams in relation to the desired beam P1. The beam coverage area (3-dB power points) are indicated by dashed lines. The relative amplitudes of undesired sidelobe envelopes in respect to the power in the desired beam are shown. The isolation level is then determined by the sum of the power of these sidelobes divided by the power in the desired beam. Section C shows that a lens with a diameter of approximately 800 wavelengths produces a maximum interbeam isolation of about 28 dB for each 100 beam reuse group.

MULTIPLE BEAMS LENS CONSTRUCTION ANALYSIS

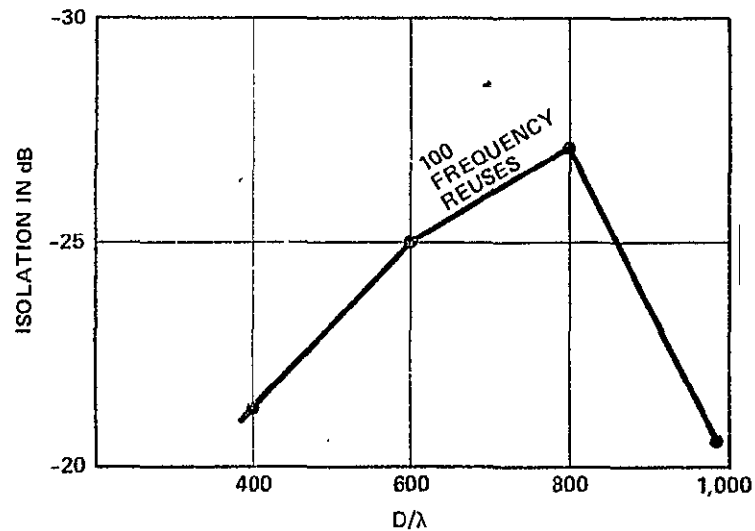
35280

A. MINIMUM DISTANCE BETWEEN TWO FREQUENCY REUSE BEAMS ($\sim 0.406^\circ$)

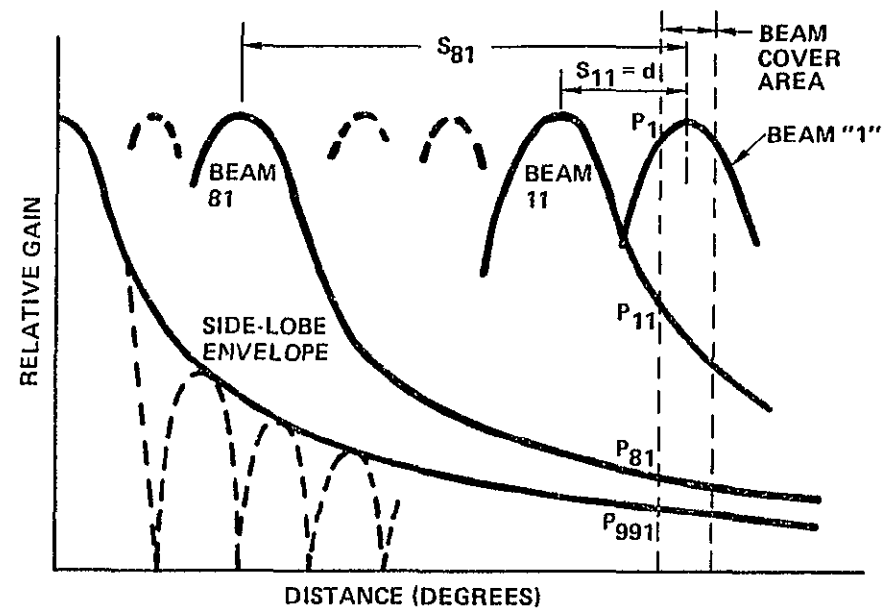


1000 BEAMS, 100 FREQ REUSES

C. ISOLATION WITH FREQUENCY REUSE



B. SIDELobe ISOLATION

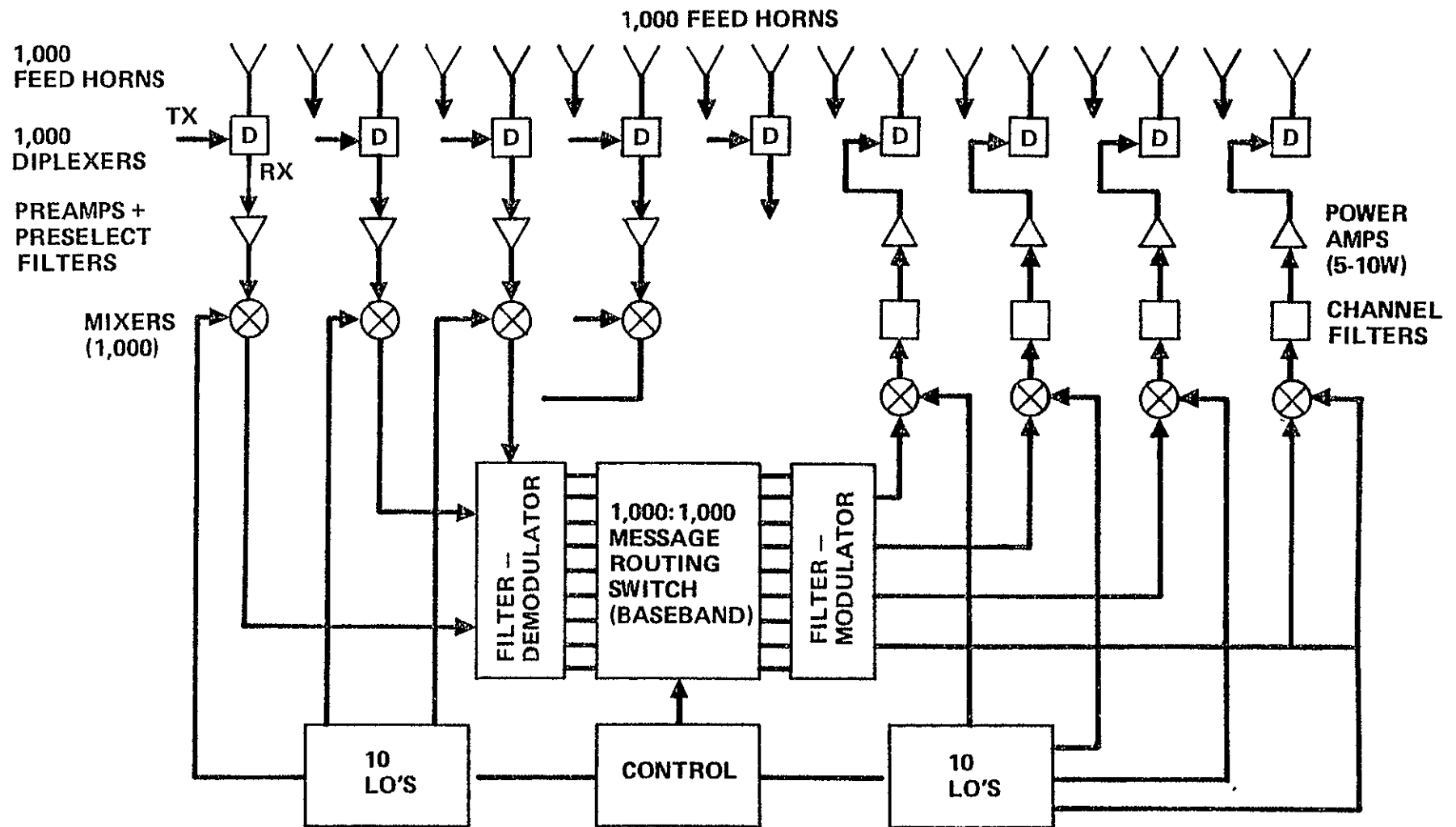


$$\text{ISOLATION LEVEL} = \frac{P_{11} + P_{21} + \dots + P_{21} + \dots + P_{991}}{P_1}$$

As shown on the facing page, the antenna feed system's 1,000 horns are connected to diplexers which connect the preamplifiers and preselect filters to the mixers during reception and to the power amplifiers for transmission. Ten local oscillators provide for the generation of the intermediate frequencies which are filtered and demodulated to obtain the data signals prior to their being switched (directed) to the modulator and up converted for transmission. Message switching would require the decoding of address bits in this concept. They would be added by the ground transmitting system.

MULTIBEAM ANTENNA FEED SYSTEM (TRANSPONDER-INTERCONNECT)

35278



The effort described in this document to this point has been directed toward briefly reviewing the future need for geosynchronous information services platforms to the year 2000, examining current capabilities, and identifying potential gaps in meeting the projected demand. By examining both telecommunications functions and growth requirements, it should then be possible to hypothesize a limited number of system models that would anticipate the various classes of future needs and would provide a basis for suggesting likely system development requirements and technological growth steps necessary to meet those needs. This identification of system requirements in turn will provide a basis for identifying promising areas for support when future research and development projects are being planned and funds allocated for them.

In attempting to generate representative system models of future systems, the number of combinations which become possible were many and varied; therefore, it was deemed necessary to establish general criteria which might limit the number of candidates.

The list shown in this figure is the result of this effort. It is believed that the system concepts which are selected for use as planning models must, as a composite group, meet all of these criteria.

CRITERIA FOR SELECTION OF REPRESENTATIVE INFORMATION SERVICES SYSTEMS MODELS

1. MEET CURRENT AND ANTICIPATED REGULATORY RESTRICTIONS
2. SERVE PROJECTED USER NEEDS
3. REPRESENT TECHNOLOGY REQUIREMENTS FOR FREQUENCY USE RANGE FROM 620 MHz
TO 40+ GHz
4. REPRESENT TECHNOLOGY REQUIREMENTS FOR POINT-TO-POINT, POINT-TO-POINTS
AND MULTIPLE-ACCESS POINTS-TO-POINTS COMMUNICATION CAPABILITIES
5. REPRESENT TECHNOLOGY REQUIREMENTS FOR VOICE, VIDEO, DIGITAL, HIGH-SPEED
DATA NETWORK AND MOBILE SYSTEMS

Six telecommunications concepts were identified which, as a group, met the criteria defined on the previous page. For each of these six telecommunications functions, basic models for possible system implementation were either established or obtained from existing documentation. For each, a particular frequency range was assumed, although other ranges could have been used. Bandwidths were also assumed for the various services, although these too would be subject to modification. Link analyses were then developed to establish representative characteristics.

The characteristics are not absolute nor, when they are taken individually, are they necessarily those that would be employed in any specific future systems. As a group, however, they are representative and they do provide a framework for discussion of future needs for supporting research and technology.

COMMUNICATIONS PARAMETERS (DOWNLINK)

(VARIOUS CONCEPTS)

35810A

	(2) VOICE (COMMUNITY SERVICE)	VOICE (PERSONAL COMMUNICATIONS)	(3) VIDEO	(3) DIGITAL AND VOICE	(3) HIGH-SPEED DATA NETWORK	(3) MOBILE VOICE AND DATA
FREQUENCY RANGE (GHz)	620 - 790 x 10 ⁻³ (1)	2	12	12	20	43
BANDWIDTH (MHz)	2	2.4 x 10 ⁻³	29	36	1 x 10 ³	20 x 10 ⁻³
CAPACITY	42 VOICE	1 VOICE	1 TV	35 MBPS	1000 MBPS	VOICE/2 KB
SPACECRAFT ANTENNA GAIN (dB)	27	58	32	32	55	47
ANTENNA SIZE (M)	5 x 3	61	1	1	4	1
RADIATED POWER (W) PER CHANNEL	11.5 (1 MULTIPLEXED CHANNEL = 42 VOICE CHANNELS)	160 x 10 ⁻³	20	100	25	2
EARTH STATION ANTENNA GAIN (dBW)	24	-6	55	60	64	32
ANTENNA SIZE (M)	3	NA	7	11	11	0.3
RECEIVER NOISE TEMP (°K)	400	600	330	50	300	330
COVERAGE	CONUS	60 NMI/BEAM	CONUS	CONUS	CONUS	LOCAL

¹SHARED WITH TV CHANNELS

²ADAPTED FROM: COMMENTS OF WARC-79 SERVICE WORKING GROUP ON SATELLITE BROADCASTING - 5/23/76

³ADAPTED FROM: TECHNOLOGY REQUIREMENTS FOR COMMUNICATIONS SATELLITES IN 1980's - LMSC - 10/73,
NASA CR 114680

When considering future systems, there is a tendency to assume rather large space antennas and small ground antennas, since this allows the latter to be low cost and meet the needs of a larger segment of the world's population. However, each of these systems also have ground coverage requirements, and large area coverage may be diametrically opposed to the desire for small, low-cost ground systems with larger space antennas.

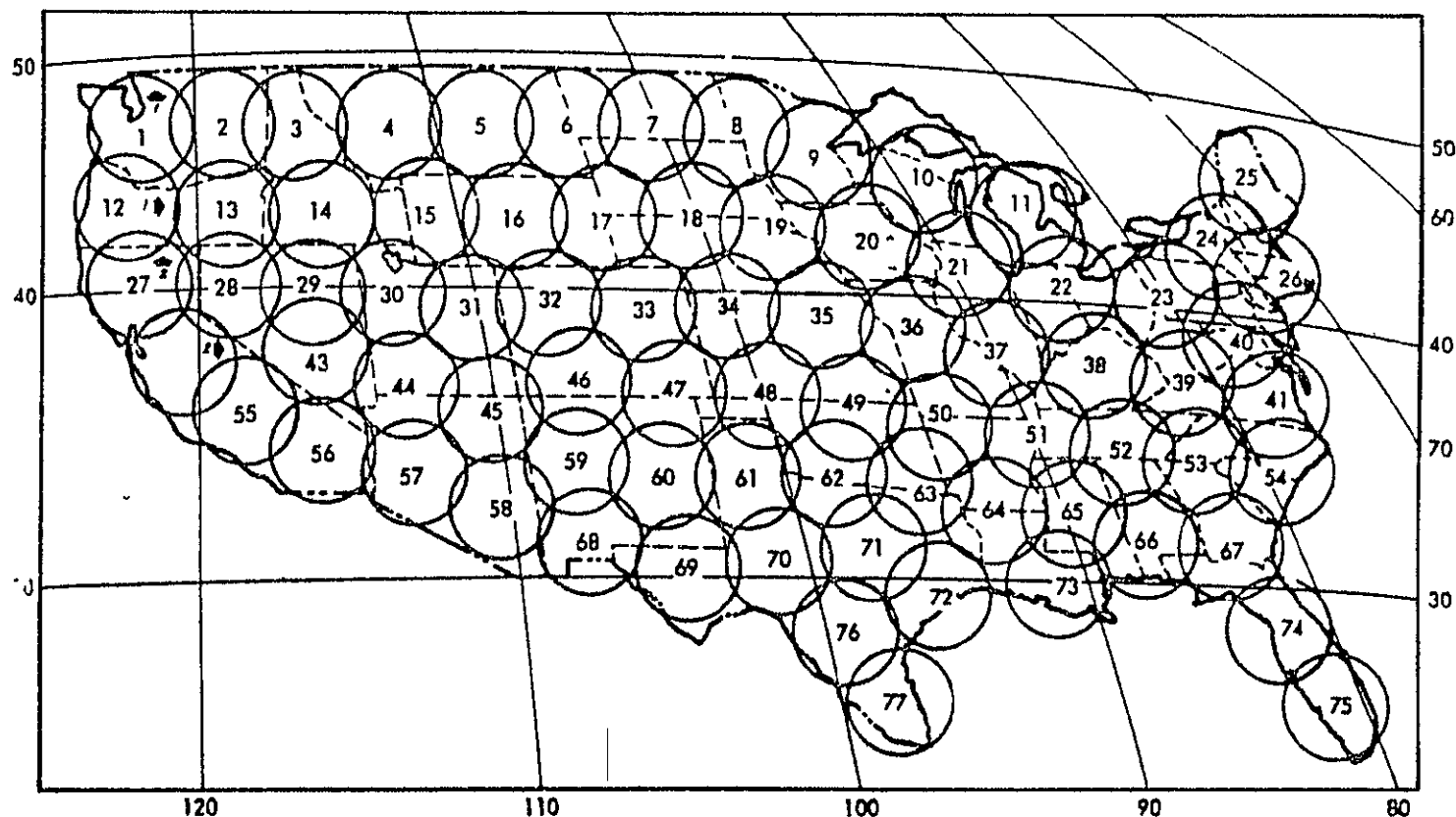
The facing chart associates satellite beamwidths with the coverages required by the communications functions. It should be noted that coverage of a global area may be provided in two ways: (1) an antenna producing a single beam or (2) an antenna producing many beams grouped in a particular fashion.

COVERAGE REQUIREMENTS

SATELLITE BEAMWIDTH (DEG)	COVERAGE	COMMUNICATIONS USE
0.5 X 0.5	LOCAL	GROUND VEHICLE NARROW B.W. TRUNKS MEDIUM RATE DATA COMMUNICATIONS
1.0 X 1.0	STATE	EDUCATION SUPPORT TELECONFERENCE COMPUTER AND DATA COMMUNICATIONS MEDICAL
2.5 X 2.5	REGIONAL	DIRECT TV COMPUTER AND DATA COMMUNICATIONS
3.5 X 7	CONUS	TELEPHONE TV NEWSPAPER COMPUTER AND DATA COMMUNICATIONS

This figure illustrates the coverage of localities comprising the CONUS with 0.5-degree beams. The fact that 77 such beams are required provides a case for the use of a multibeam antenna rather than attempt to employ individual antennas or satellites. However, it also results in a departure from simple systems since beam forming networks and multiple feeds must be used.

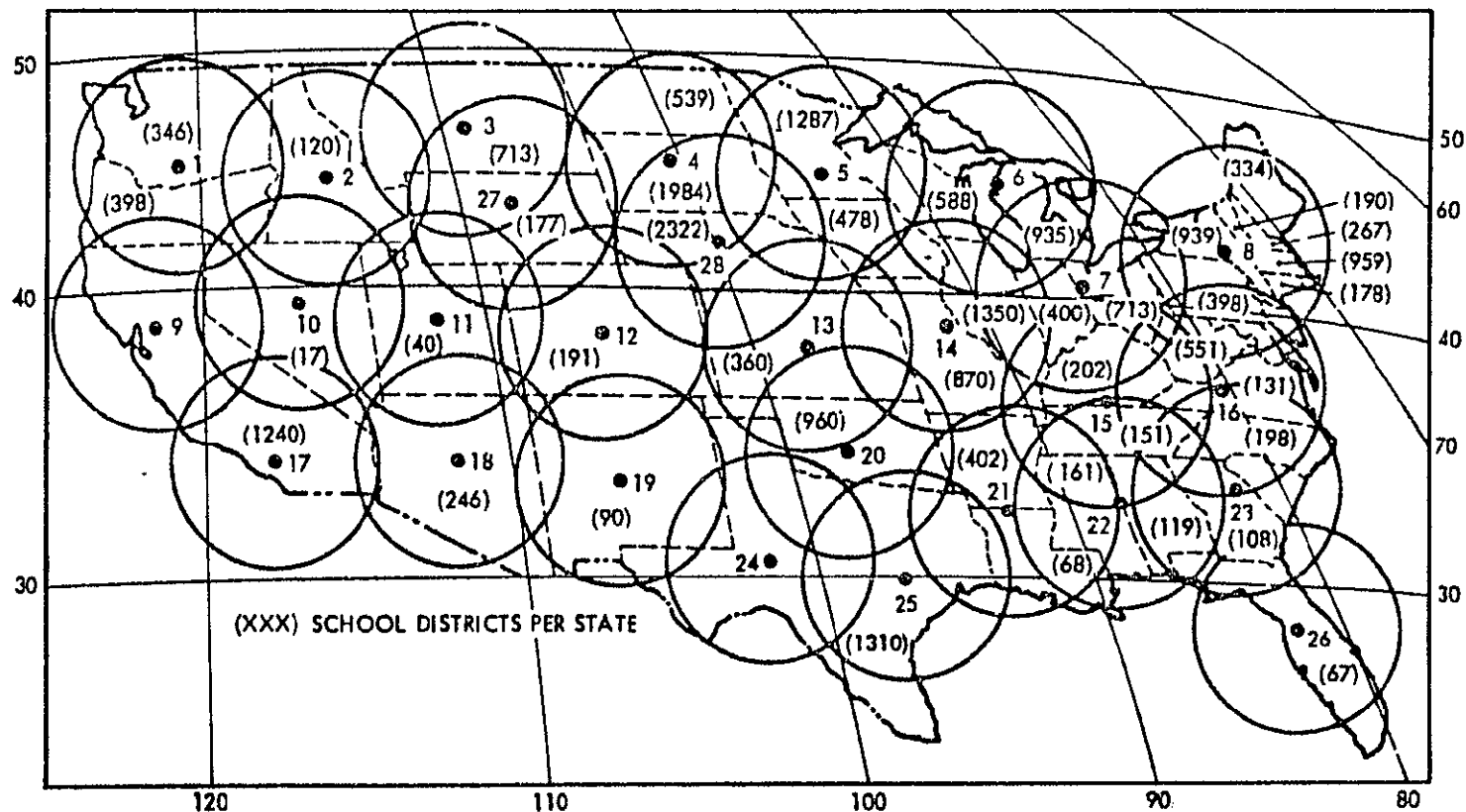
COVERAGE OF CONTIGUOUS 48 STATES BY 77 BEAMS, EACH 0.5 BY 0.5 DEGREES



SOURCE: ADAPTED FROM: TECHNOLOGY REQUIREMENTS FOR COMMUNICATIONS
SATELLITES IN 1980'S - LMSC - OCT 1973, NASA CR 114680

Using a smaller-aperture antenna or lowering the frequency of operation would result in semistatewide coverage. Implementation of such a system results in considerable overlap in the eastern regions.

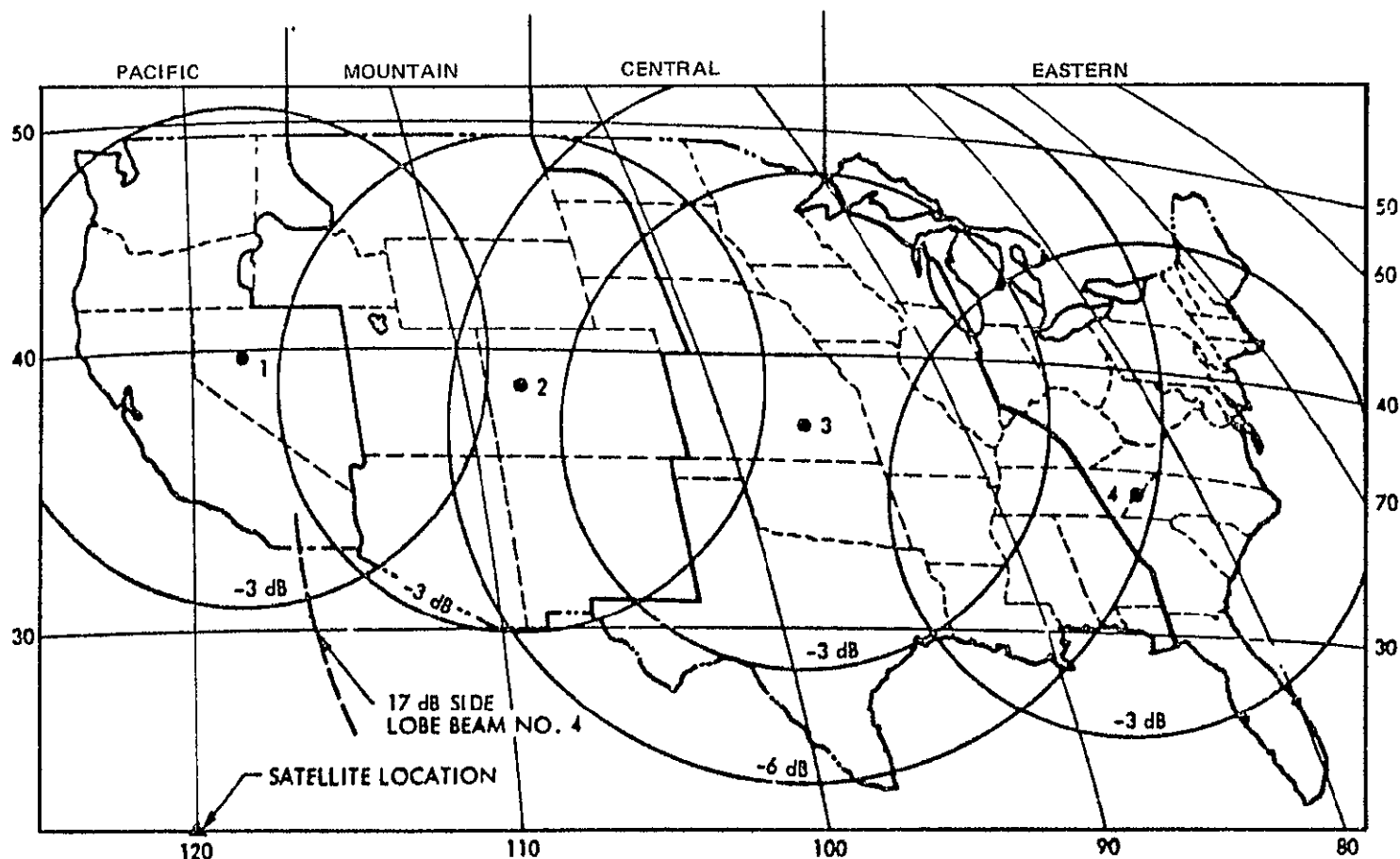
COVERAGE OF CONTIGUOUS 48 STATES - BY 27 BEAMS, EACH 1 X 1 DEGREE



SOURCE: ADAPTED FROM: TECHNOLOGY REQUIREMENTS FOR COMMUNICATIONS SATELLITES IN 1980'S - LMSC - OCT 1973, NASA CR 114680

The manner in which four beams would provide time-zone coverage is illustrated. Such a system would, perhaps, be ideal for direct TV. The necessity for rather large frequency separation is shown by the size of the -6 dB pattern of beam 3 and the -17 dB sidelobe of beam 4. Spatial discrimination does not appear to be particularly effective.

TIME ZONE COVERAGE OF CONTIGUOUS 48 STATES - FOUR BEAMS, EACH 2.5X2.5 DEGREES

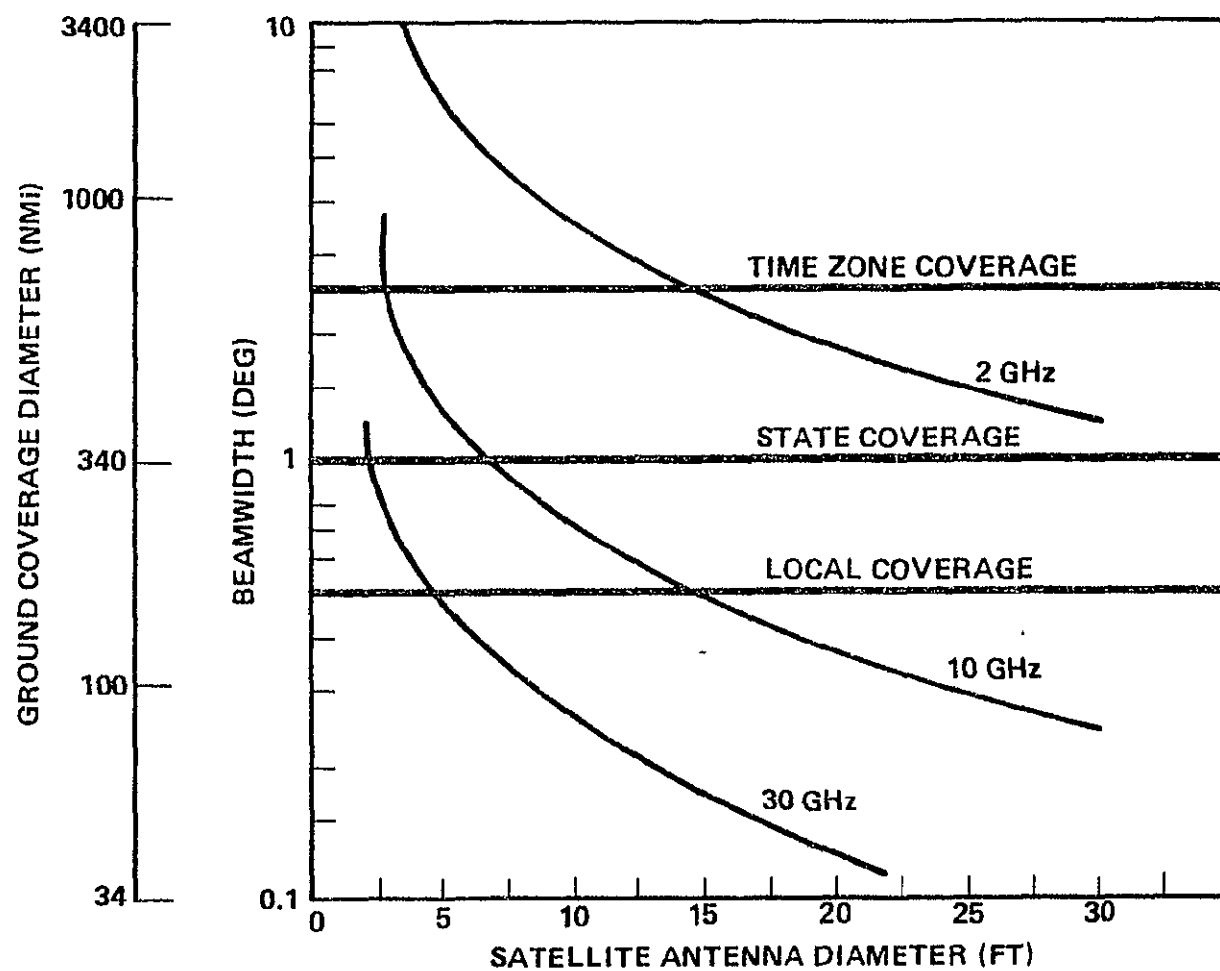


SOURCE: ADAPTED FROM: TECHNOLOGY REQUIREMENTS FOR COMMUNICATIONS
SATELLITES IN 1980'S - LMSC - OCT 1973, NASA CR 114680

This figure correlates beamwidth with satellite antenna diameter as a function of frequency of operation. It shows that if time-zone coverage is desired and the operating frequency is 2 GHz, an antenna producing a single beam cannot be larger than about 15 feet. If the frequency is much lower, antenna size can become very large indeed. However, as operating frequencies become higher, satellite antennas correspondingly become very small.

In view of the trend toward use of the higher regions of the radio spectrum, the need for large antennas becomes questionable unless multiple beams are to be employed and/or the points of reception are few in number. One may, of course, also postulate a telecommunications capability in which the area of ground coverage is reasonably small but variable as in the case of a system designed for use during disasters.

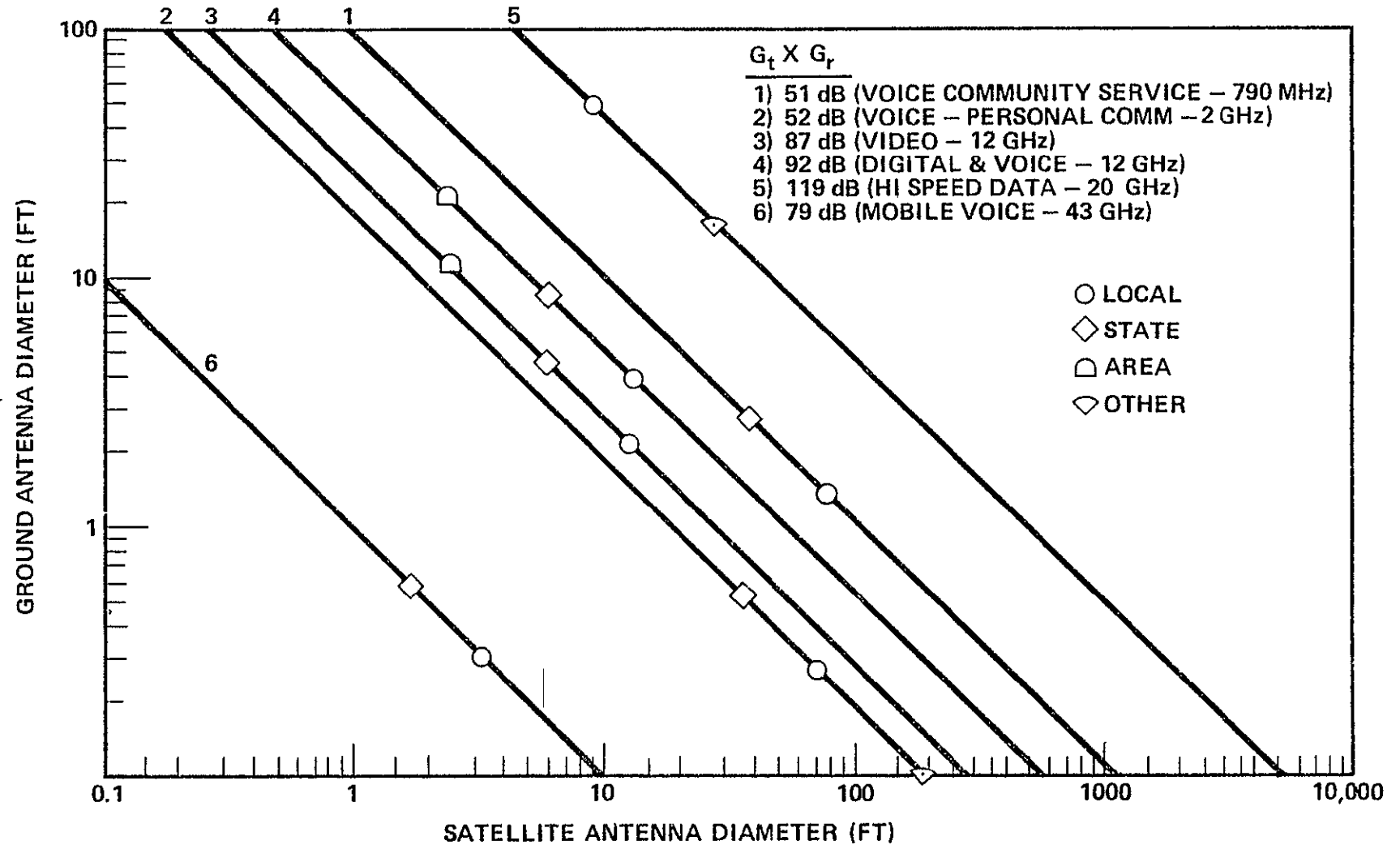
ANTENNA SIZE VS GROUND COVERAGE



For each of the models hypothesized earlier in chart 35810A, ground and satellite antennas were defined for a constant antenna gain product. The resultant antenna diameters for local, state, area, and other (extremely narrow beam) were then plotted with the lines representing the gain products.

It is seen that the antennas for voice community service (Line 1) can result in satellite antenna diameters from about 30 to 70 feet. Personal communications can require an antenna as large as 200 feet if the ground unit (wrist radio) antenna gains are sufficiently low. For all the other services, satellite antennas are relatively small and do not appear to warrant assembly on-orbit.

SATELLITE ANTENNA SIZE LIMITATIONS

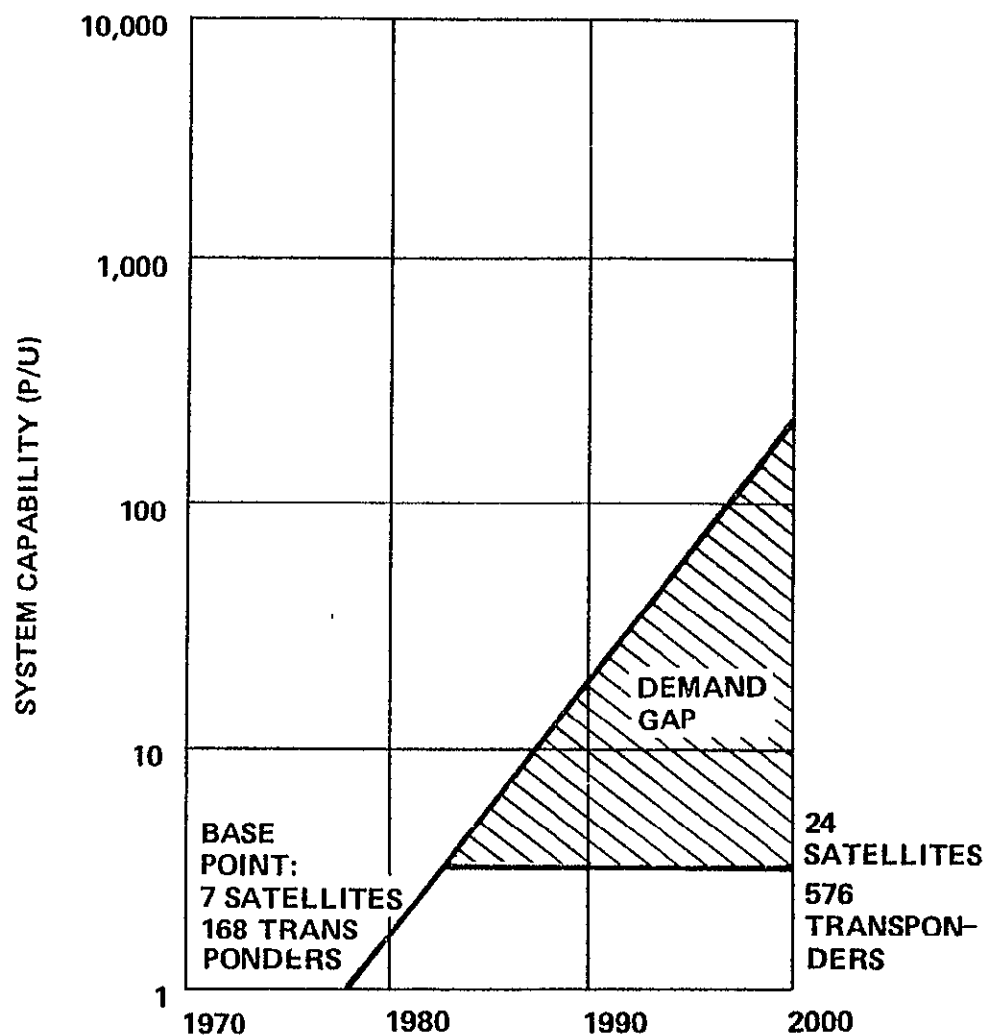


KEY TECHNOLOGY DRIVERS

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It was pointed out earlier that aside from purely economic considerations, there are technological and political barriers to be overcome in closing the demand gap. The basic problem which must be addressed is to increase, by whatever means necessary, the telecommunications system capacity. The defining equation of the system capacity is very complex and includes, for example, factors such as those listed on the facing chart. The list is intended to be neither complete nor comprehensive. Rather it is intended to illustrate the many types of factors that need to be addressed in meeting future demands.

FACTORS TO BE CONSIDERED IN CLOSING THE DEMAND GAP



FACTORS IN THE SYSTEM CAPABILITY EQUATION:

NO. OF SATELLITES
NO. OF GROUND STATIONS
OPERATING FREQUENCIES
CODING/MODULATION TECHNIQUES
LINK QUEING ASSIGNMENTS
RECEIVER SENSITIVITY
TRANSMITTER POWER
ANTENNA PERFORMANCE
BEAM WIDTH
COHERENCY/CORRELATION
COMPONENT PERFORMANCE
LIMITS OF PHYSICAL PRECISION
OVERALL SYSTEM PERFORMANCE
MESSAGE STRUCTURE

The list of factors in the system capability equation described in the preceding chart are restated here. For each factor, there can be a number of technological areas within which advances can lead to solutions or partial solutions of the problem. In addition, there are matters of policy which also must be addressed. This chart illustrates the breadth of the approach necessary to increase system capability.

Six of the 14 factors illustrated are related to both policy and technology matters. For example, as previously described, operational frequencies are determined not entirely by natural characteristics but by assignments made as a result of international agreements and federal laws, rules, and regulations. The resolution of problems of this type requires long-term political action which may prove in a social sense to be impossible to achieve.

In certain cases, solutions to technical factors will require instigation of a directed research and development project. Research directed primarily at ascertaining the mechanism of some process or behavioral phenomena is necessary in addition to research aimed at component fabrication and integration. A concerted effort along these lines is currently being undertaken within the electronics industry. The R&D budget within the US telecommunications equipment and service industries amounts to about \$6 billion annually.

On the other hand, solutions to some of the factors will require advances in spacecraft, space transportation, and orbital operations technologies, and these problems are not being addressed currently by the electronics industry. For example, antenna performance and beamwidth are functions of absolute aperture and physical precision of systems operating at geostationary orbital locations. For antennas larger than can be delivered and deployed by one Shuttle flight, space construction techniques will be required. This critical technology needs to be developed and demonstrated in order to reduce the technical uncertainty in implementing these concepts to the point where private venture capital would be attracted for specific system development.

Overall, the solution of the system capability equation will require not only a solid systematic engineering approach involving a wide range of divergent yet correlated technologies, but also will require the efforts of enterprising businessmen who can focus on long-term project goals which offer excellent profit motivation

SYSTEM CAPABILITY EQUATION

35275

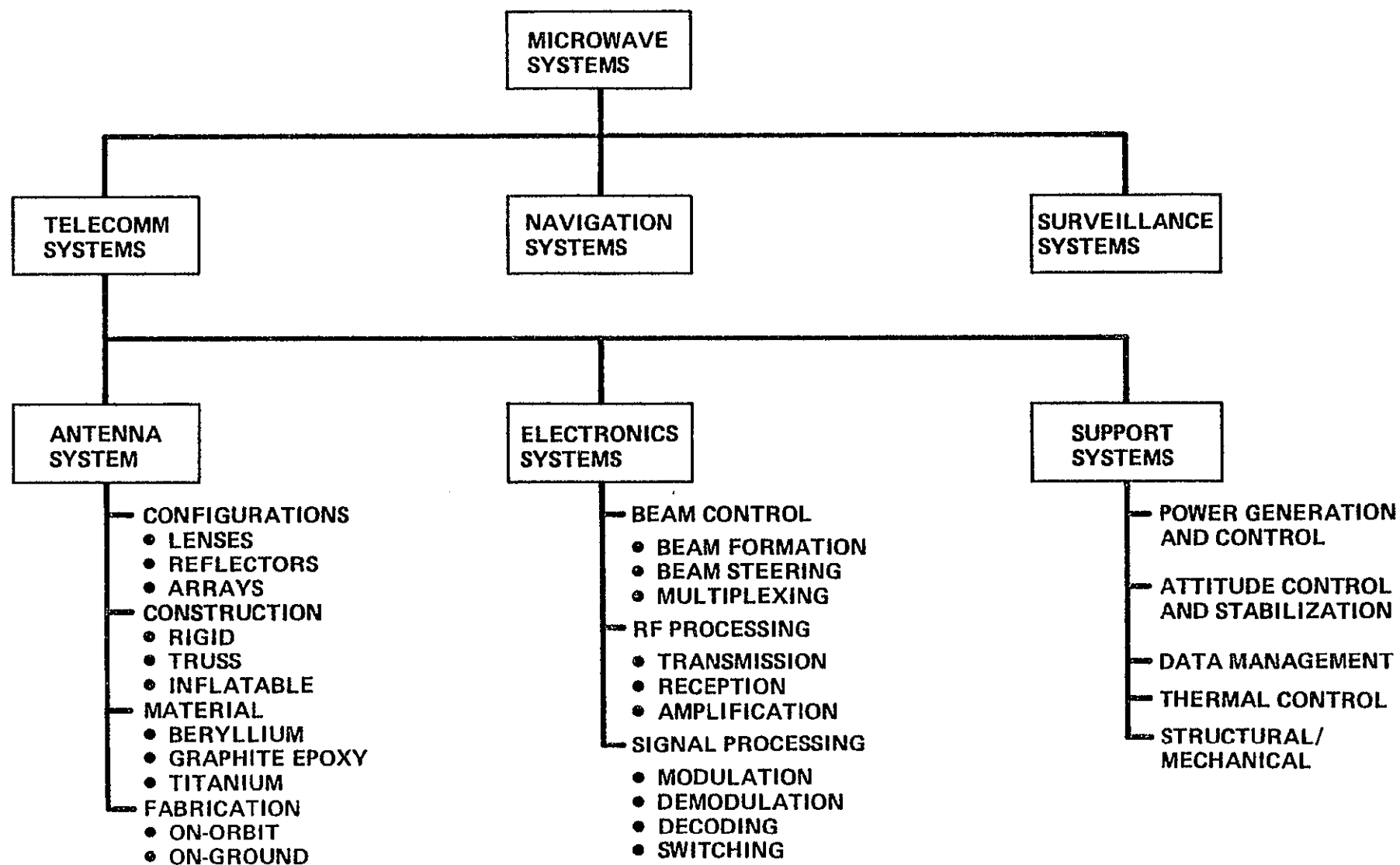
FACTORS IN THE SOLUTION	POLICY	TECHNOLOGY				
		ELECTRONIC R&D	GROUND STATION	SPACE- CRAFT	SPACE TRANS- PORTATION	ORBITAL OPERATIONS
NO. OF SATELLITES	✓			✓	✓	✓
NO. OF GROUND STATIONS	✓		✓			
OPERATING FREQUENCIES	✓	✓	✓	✓		✓
CODING/MODULATION TECHNIQUES		✓				
LINK QUEING ASSIGNMENTS		✓				
RECEIVER SENSITIVITY		✓	✓	✓		
TRANSMITTER POWER	✓	✓	✓	✓	✓	
ANTENNA PERFORMANCE		✓	✓	✓	✓	✓
BEAM WIDTH	✓		✓	✓		✓
COHERENCY/CORRELATION		✓				
COMPONENT PERFORMANCE		✓				
LIMITS OF PHYSICAL PRECISION				✓		✓
OVERALL SYSTEM PERFORMANCE		✓	✓	✓	✓	✓
MESSAGE STRUCTURE	✓	✓				

Before defining technology needs, it was believed that an organizational framework for spacecraft microwave system development was required in order to visualize common needs and to clarify where such needs exist. This figure is intended to suggest such an organizational structure. At the first level, major system types falling in such microwave categories as telecommunications, navigation, and surveillance are indicated. Since we are primarily concerned with telecommunications, only its constituents are taken to the next (system) level.

Within the antenna system category, for example, a number of configuration options exist which may be used depending on system requirements. The construction of the antennas will generally vary with the size and type of configuration selected. Materials also will vary depending upon the particular structural element in question although graphite epoxy is presently favored where large assemblies are required due to its stiffness and expansion qualities. Depending upon its size, the need for fabrication, whether on-orbit or ground, would establish another level of requirements to be satisfied.

The electronics system breakdown is conventional. Industry is currently devoting resources to improve existing RF and signal processing and to extend the frequency range of hardware. However, within the support systems area, space-unique issues need continuing support. Of these support systems, the attitude and stabilization technologies are most critical in future system implementation concepts.

MICROWAVE SYSTEM STRUCTURE



The six model telecommunications concepts described earlier (Chart 35810A) represent four broad system types: voice, video, low data rate, and high data rate. This figure describes the technology needs of these four broad system types. Within the antenna systems, development of antennas with multiple-beam capability to reduce sidelobes and interference is needed. Beam contouring which permits the concentration of power where needed, such as being done by the Japanese broadcast satellite, is a corollary requirement. On the ground, low-cost mass-produced antennas with low-cost pointing/tracking systems to ensure maximum utilization of the effective area coverage will enable wide use of the services offered.

Electronic systems must improve equipment for reception and transmission at higher frequencies. Data compression systems will improve the utilization of existing parts of the spectrum.

Support systems will allow the economies of size for orbiting systems to be exploited. Transport, on-orbit maintenance, and grouping of systems must all be developed simultaneously to make use of the platform concept.

AREAS WHERE DEVELOPMENT IS REQUIRED

35811

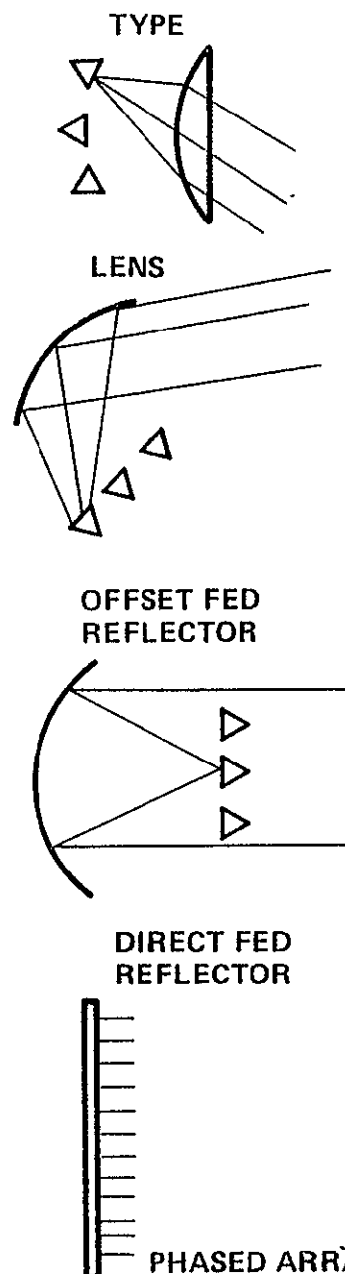
TECHNOLOGY NEEDS	SYSTEMS CONCEPTS			
	VOICE	VIDEO	LOW RATE DATA	HIGH RATE DATA
ANTENNA SYSTEMS				
• MULTIPLE BEAMS	✓	✓	✓	
• IMPROVED BEAM CONTOURS		✓	✓	✓
• LOW-COST GND ANTENNAS	✓	✓	✓	
• LOW-COST GND TRACKING	✓	✓	✓	
ELECTRONIC SYSTEMS				
• LOW-COST PREAMPLIFIERS	✓	✓	✓	
• DATA COMPRESSION		✓		✓
• HIGH-POWER/HIGH-FREQUENCY AMPLIFIERS		✓		✓
• SWITCHING	✓			✓
SUPPORT SYSTEMS				
• ORBITAL TRANSPORT	✓	✓	✓	✓
• SERVICING AND MAINTENANCE	✓	✓	✓	✓
• PLATFORMS	✓	✓	✓	✓

The various types of antennas for on-orbit use capable of multiple beam operation are shown on the facing chart. Their advantages and disadvantages are listed to explain why one type may be preferred over another. This does not imply that any type is superior to another for a given application but does indicate that requirements analysis must be conducted carefully prior to a selection.

At the present time, the offset-fed reflector appears to be the leading candidate for telecommunications applications. As the number of beams and spatial coverage increase, the attractiveness of the lens also increases.

TELECOMMUNICATIONS ANTENNA TYPES

35812A



ADVANTAGE

• LOW ABERATION BEAMS

- EASE OF CONTROL

• DESIGN SIMPLICITY

- INHERENT BANDWIDTH
- EASE OF CONSTRUCTION
- LIGHT WEIGHT
- LOW COST
- ALREADY DEVELOPED

• DESIGN SIMPLICITY

- INHERENT BANDWIDTH
- EASE OF CONSTRUCTION
- LIGHT WEIGHT
- LOW COST
- ALREADY DEVELOPED

- CONTINUOUS CONTROL OF BEAM SHAPE

• HIGH-GAIN, LOW-SIDELobe BEAMS

- GEOMETRY
- RELIABILITY

KEY CONSIDERATION

DISADVANTAGE

• DESIGN COMPLEXITY

- HIGH COST
- REQUIRES DEVELOPMENT

• SIDELobe DETERIORATION WITH SCAN

- BEAM BROADENING WITH SCAN

• APERTURE BLOCKAGE

- HIGH SIDELobe LEVELS
- LARGE ABERATION

- HIGH WEIGHT

• DESIGN COMPLEXITY

- HIGH COST
- LOW XMTR EFFICIENCIES
- REQUIRES FURTHER DEVELOPMENT

To further describe the six satellite models (concepts) previously discussed in terms of Communications Parameters (Chart 35810A), subsystem support requirements were estimated for each. For voice (community service) and assuming single-channel-per-carrier links, each with 2 MHz bandwidth could contain 42 voice channels. Of 6 adjacent UHF channels, 3 would be allocated for transmission and 3 for reception. If each satellite were to operate in 5 bands, 173 watts would be generated at 11.5 watts per channel transmitted. All stabilization requirements shown were established as 10% of the bandwidth. Thermal control (heat rejection) was sized on the basis of 3 two-way voice channels per watt and 630 channels or 210 watts. Surface accuracy of the antenna was sized for a maximum gain loss of 1 dB.

The voice (personal communications) power was based upon an assumption of 160 milliwatts of power per channel times 1000 channels per beam times 25 beams for a total of 4 kW. Its heat rejection requirement was based on 10 channels per watt or 2500 watts. If the power conversion to RF energy efficiency is assumed to be 50%, then 2 kW must be rejected from the transmitter packages, leaving 500 watts for the rest of the systems which appears to be reasonable.

It was assumed that a 4-channel direct broadcast video system might be employed, requiring 80 watts of radiated power. Heat rejection was estimated at 40 watts for the TWTs and 250 watts for the satellite systems, or 290 watts total.

Four model systems per satellite also were assumed for both digital system models and their heat rejection requirement was estimated in the same manner as that for the video systems. Four systems at 50 channels per system were also assumed for mobile voice and data.

SATELLITE SUPPORT SYSTEM LEVELS

SUPPORT SYSTEM	VOICE (COMMUNITY SERVICE)	VOICE (PERSONAL COMMUNICATIONS)	VIDEO	DIGITAL AND VOICE	HIGH-SPEED DATA NETWORK	MOBILE VOICE AND DATA
RF POWER GEN- ERATION ● LEVEL (W)	173	4 K	80	400	100	400
ATTITUDE CON- TROL AND STABILIZATION ● STABILITY (DEG)	0.7	0.015	0.4	0.4	0.03	0.07
THERMAL CON- TROL ● HEAT RE- JECTION (BTU/HR)	710	8,500	985	1,500	1,000	1,500
STRUCTURAL ● RMS SUR- FACE ACCU- RACY (CM)	2.3	0.94	0.16	0.16	0.09	0.04

The options for meeting future needs and reducing system costs as we understand them are shown on the accompanying figure. It must be noted that the options are not necessarily capable of doing both, i. e., operation at low frequencies does not appear to meet future needs (with the exception of innovative systems such as that proposed by the WARC working group for voice broadcasting via satellite). It is, however, a relatively low-cost system due to equipment availability. On the other hand, the use of high-gain space antennas appears to satisfy both future needs and the desire to reduce system costs due to the present high cost of ground systems.

Placing multiple systems on a single space platform is an interesting concept which would help meet future needs. Its cost aspects are uncertain at this time, however, due to the large amount of development required before it can be applied practically. As a result, it is considered a high-risk option.

Low-cost equipment development is expected to be a natural result of competition within the electronics industry. Based upon present trends, these systems will emerge without further Government (NASA) support.

Intersatellite communications will eliminate ground station/satellite hopping of transmissions in order to reach widely separated communications points. As a by-product, it would also improve message quality. It will serve to unload communications links and, perhaps, reduce the number of ground systems required.

The following four figures touch upon several of these key considerations in further detail.

OPTIONS FOR MEETING FUTURE NEEDS AND REDUCING SYSTEM COSTS

OPTION	COMMENT
• OPERATION AT LOWER FREQUENCIES	• SPECTRUM CONGESTION • EQUIPMENT AVAILABLE
• USE OF HIGH GAIN SPACE ANTENNAS	• NARROW BEAMWIDTHS MULTIPLE ANTENNAS OR MULTIBEAM ANTENNAS • ON-ORBIT SWITCHING
• MULTIPLE SYSTEMS ON SPACE PLATFORM	• ON-ORBIT ASSEMBLY
• LOW COST RF EQUIPMENT DEVELOPMENT	• HIGH FREQUENCY • LOW NOISE • DIGITAL SYSTEMS • GROUND ANTENNA POINTING
• INTERSATELLITE COMMUNICATIONS	• LASER SYSTEM

High-gain antenna systems may be employed in many applications. We have mentioned one for electronic mail, another for personal voice communications, and present here another concept for use in a mobile disaster system. For this application, a gain of 61 dB is required. However, the antenna size is only 3.4 meters due to the high frequency employed in transmission and reception (43 GHz).

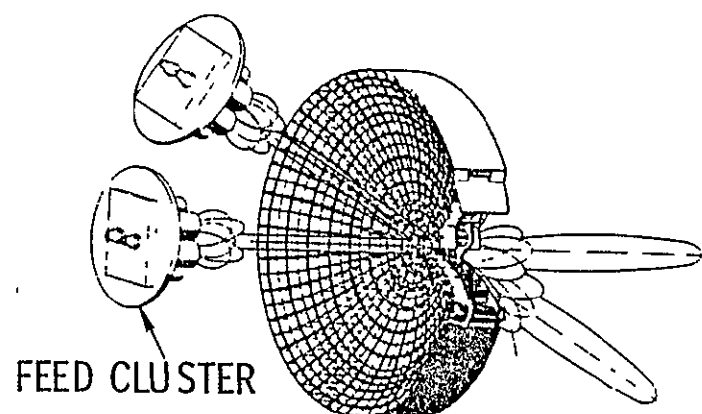
An antenna beamwidth of 0.15 degrees would subtend a 25 nautical mile (3 dB points) diameter area on the ground which might be adequate for local communications of this type. With the ability to select the proper feed horns (cluster), coverage could be provided when and where needed and one such satellite would suffice for the CONUS.

Due to the large signal fades reported at the higher frequencies by rain (10 to 15 dB from ATS-6 results), some method of reducing the problem appears to be needed. One method might be to provide variable gain power amplifiers which would increase power during storms and then reduce power output in clear weather to remain within the regulatory energy density constraints.

For this system, a ground antenna gain of only 18 dB would be required.

HIGH GAIN ON-ORBIT ANTENNA SYSTEMS

CHARACTERISTICS



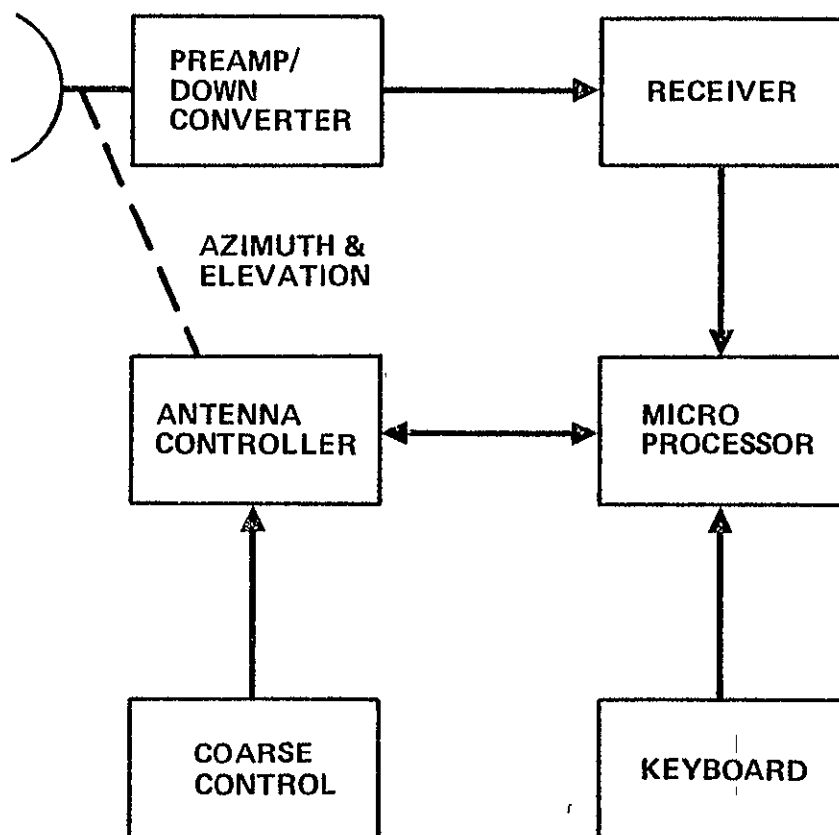
- ANTENNA GAIN - 61dB
- ON-ORBIT ANTENNA DIAMETER - 3.4M
(43 GHz - MOBILE DISASTER SYSTEM)
- ANTENNA BEAMWIDTHS - 0.15 DEG
- GROUND COVERAGE / BEAM - 2000 NMI^2
- SELECTABLE POINTING COORDINATES
- VARIABLE GAIN POWER AMPLIFIERS
(FADE RANGE AT 30 GHz - 10 TO 15 dB
FLUCTUATIONS)
- GROUND ANTENNA GAIN - 18 dB

While narrow-beam space antennas reduce the requirement for large ground antenna gains, an adequate signal margin still depends upon a reasonable ground antenna effective area. This area can be seriously degraded if the antenna is not pointed at the broadcast satellite. In addition, although the ground antenna size requirements are expected to continue to decrease, the change may be largely attributable to the use of higher frequencies, and antenna beam widths may be quite narrow. For uplink transmission, pointing problems could result in either nonreception by the satellite or interference with another satellite.

A reasonably precise, low-cost antenna tracker may, therefore, be worth considering. Since microprocessors are becoming relatively common with many applications, their future use for this function seems probable. Whether the antenna controller could be produced at an acceptable cost is unknown. However, if the target cost could be achieved, a potential market appears to exist.

PRECISE ANTENNA TRACKER

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CHARACTERISTICS

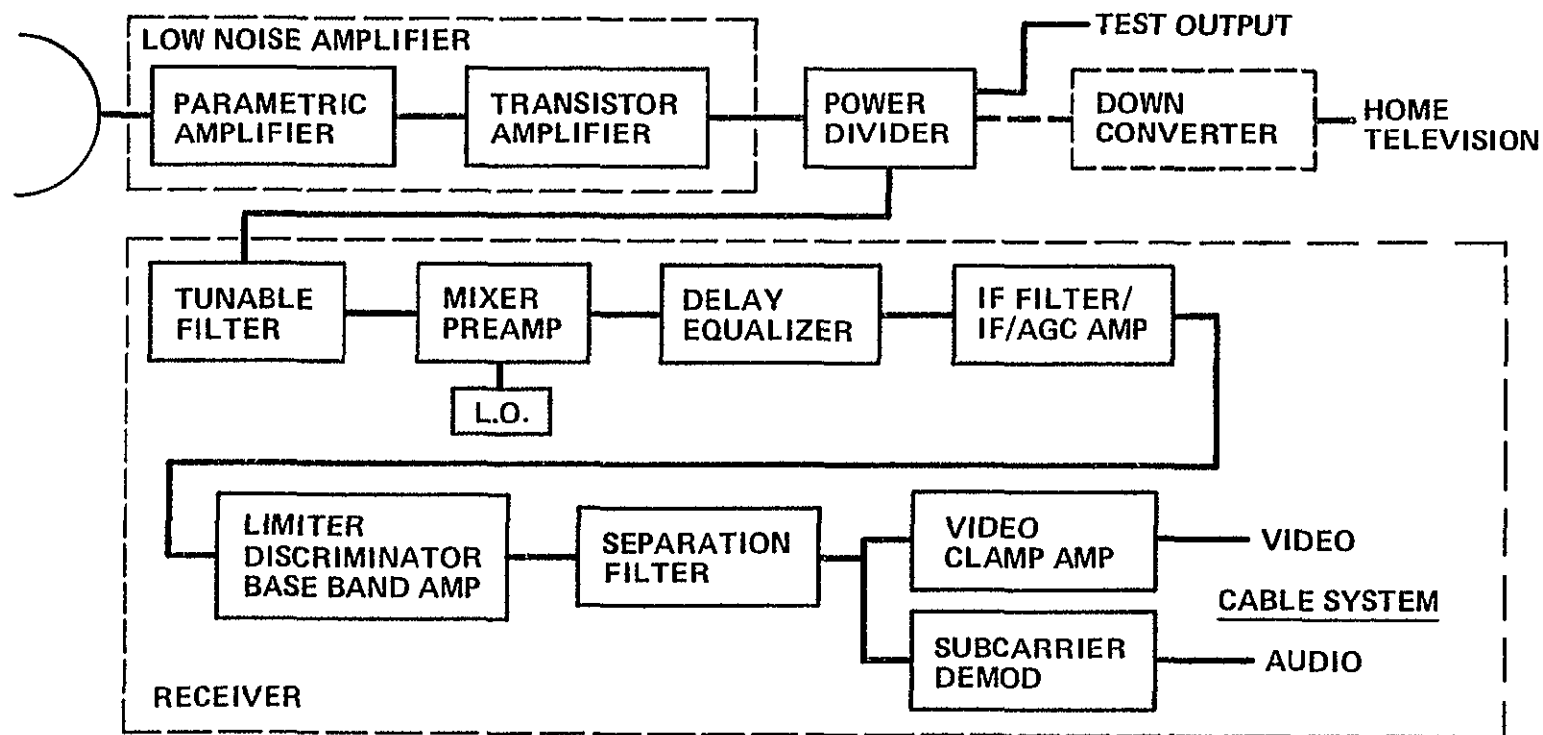
- TARGET COST $\approx$ \$1000
- INITIAL COARSE POINTING - MANUAL
- AUTOMATIC POINTING
- HOMING ON SIGNAL STRENGTH AND FREQUENCY

There are two options for reception of video signals; direct to the home or to a cable television terminal. In either case, low-cost, low-noise preamplifiers are required.

As shown in the chart, a down converter would be required for use with existing television receivers if the 11 to 12 GHz band is used. For cable TV, a receiver would be required as shown. In the United States, cable TV use is expanding rapidly and for cost-effective reception, appears to be the approach that will be adopted. In less-developed countries, direct reception may be the best approach.

Ground terminal performance for the 11 to 12 GHz bands is presently capable of meeting the indicated specifications. Since this band is not capable of satisfying all forecast needs, these characteristics must be met at higher frequencies. Industry is presently developing the equipment to provide this performance and no additional support appears to be required.

VIDEO RECEPTION OPTIONS



GROUND TERMINAL PERFORMANCE REQUIREMENTS DEVELOPMENT AT HIGHER FREQUENCIES

SERVICE	G/T	EIRP	RF BANDWIDTH	RECEIVER	ANTENNA SIDE LOBE LEVELS
(1) VOICE/DATA/IMAGERY (2-WAY)	16 dB/K	45 dBW	50 kHz TRANSMIT/RECEIVE	4 dB	20 dB DOWN
(2) VOICE/DATA/IMAGERY (1-WAY)	16 dB/K	—	50 kHz RECEIVE	4 dB	20 dB DOWN
(3) VIDEO (2-WAY)	20 dB/K	72 dBW	25 MHz TRANSMIT/RECEIVE	4 dB	20 dB DOWN
(4) VIDEO (RECEIVE ONLY) & VOICE (2-WAY)	16 dB/K	45 dBW	25 MHz RECEIVE & 50 kHz TRANSMIT	4 dB	20 dB DOWN

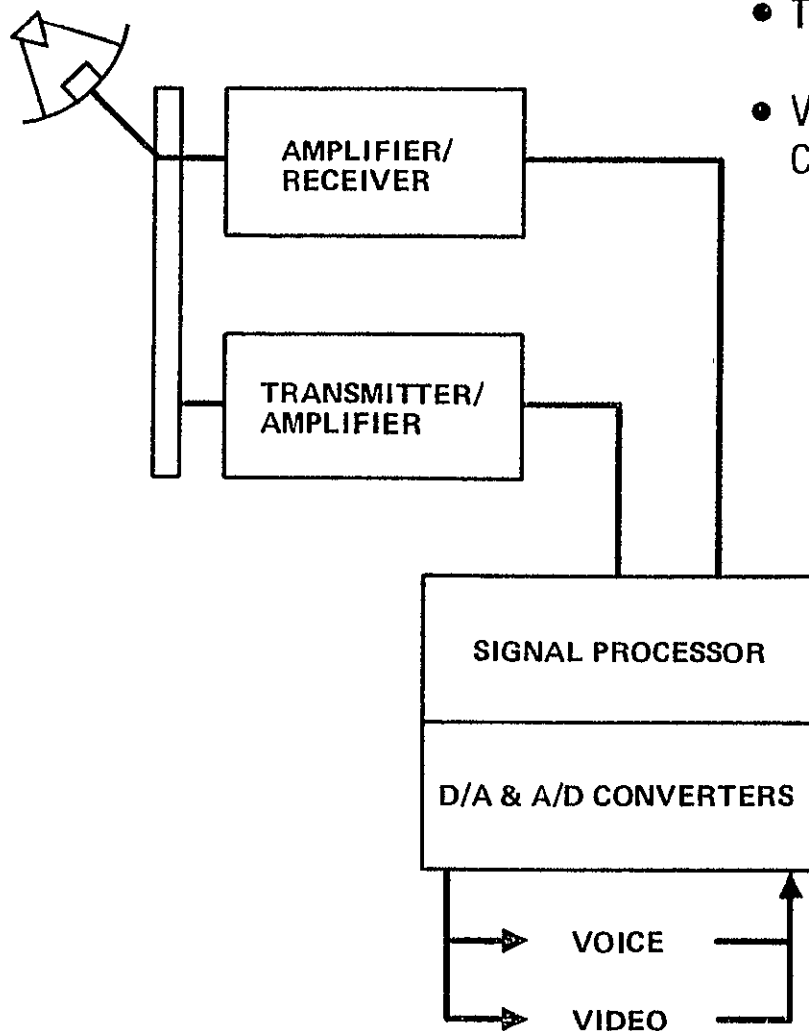
One of the major reasons for the crowded spectrum is the operational bandwidths required by present systems. The improvements in signal-to-noise ratios afforded by digital systems are at the expense of bandwidths. However, it is expected that bandwidths can be reduced to approximately one-fifth of their present size with data compression techniques.

Some of the present and prospective data rates for various types of services are shown. Additional circuitry will be required to permit these reductions, which results in another challenge — that is, to provide this added circuitry at minimum cost.

TRANSITION TO ALL DIGITAL SYSTEMS

CHARACTERISTICS

- TIME DIVISION MULTIPLEXING OF ALL SIGNALS
- VIDEO/VOICE ANALOG SIGNAL ENCODING AND COMPRESSION
 - VOICE: 64 KBPS/CHANNEL TO 9.6 KBPS/CHANNEL
 - VIDEO: 92.5 MBPS TO 20 MBBS/CHANNEL
 - PICTURE PHONE: 6.3 MBPS TO 1.2 MBPS

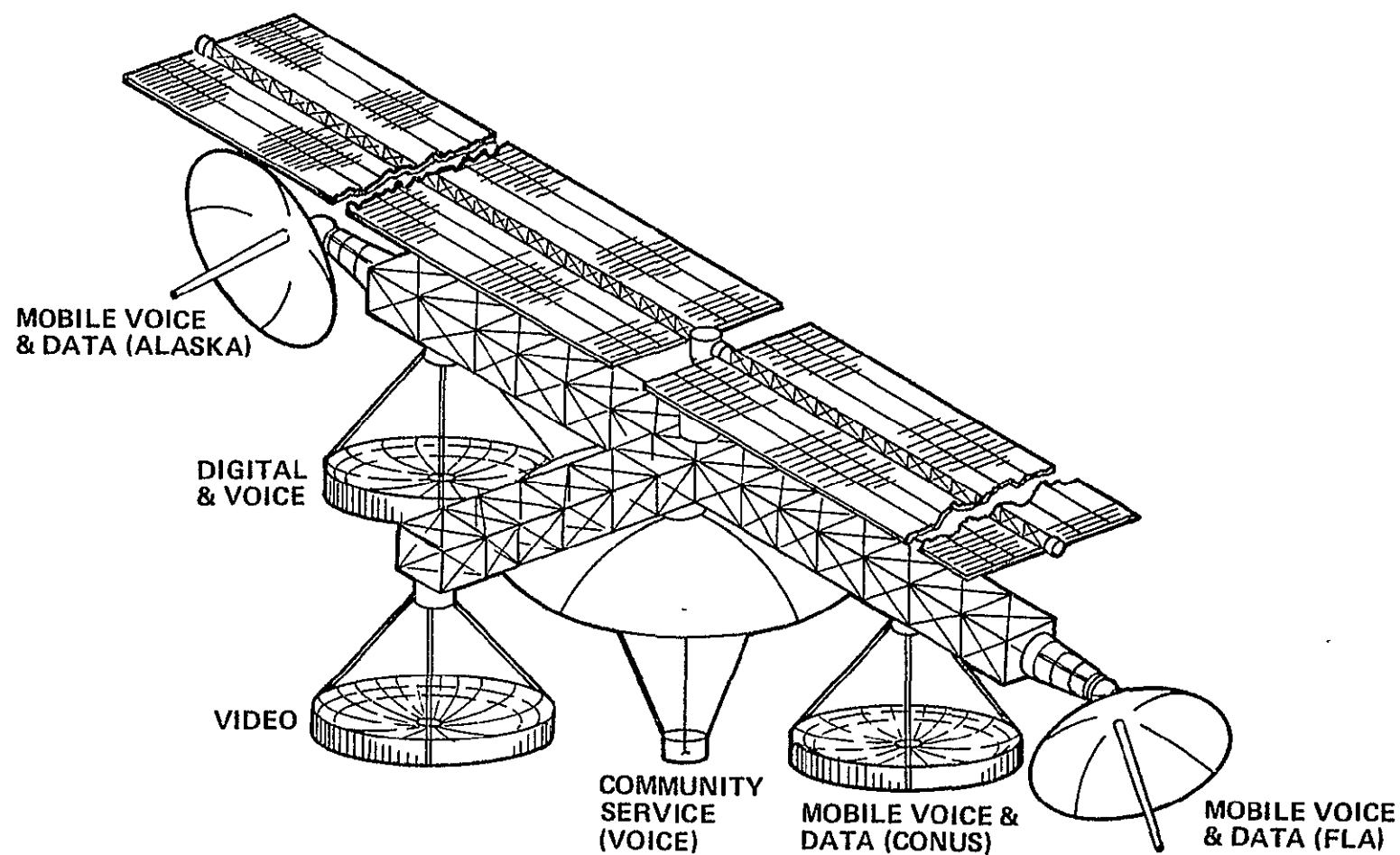


As noted earlier, placing multiple telecommunication functions on a single platform is an interesting concept which would help meet future needs. An illustration of the platform concept is shown which employs systems for some of the services which have been previously discussed. It is not to scale. Since only a single power, guidance, navigation, stabilization and data management system would be required, considerable savings in development and hardware could result. This may be offset by the cost of support services.

The following are potential advantages of the platform concept:

- Efficiencies of size
 - Shared power system
 - Shared thermal control system
 - Shared propulsion, G&N system
- Efficient use of Shuttle transport
- Efficient use of on-orbit servicer
- Reduction in operations control centers
- Combination of DOMSAT, PSCS systems
- Reduction of mutual antenna interference through frequency separation
- Reconfiguration of separation to meet changing needs
- Improvement of channel utilization, S/N ratios through platform-to-platform data transmission.

PLATFORM CONCEPT



While the platform concept would allow many systems to use the same basic resources and has many positive aspects, it also has some problems to be overcome. These potential problems break down into organizational and technical areas.

It is believed that the technical problems are amenable to solution if a properly supported effort is undertaken. One of the more difficult and costly problem areas will be the development of a vehicle needed to transport the platform to synchronous orbit once it is assembled. Such an orbital transport vehicle could also be used for servicing the platform. The implementation of an orbital transport vehicle concept, however, appears to require no new technical breakthroughs.

SHARED SYSTEM PROBLEMS

ORGANIZATIONAL

1. RESPONSIBILITY FOR SYSTEM DEVELOPMENT
2. RESPONSIBILITY FOR SYSTEM MANAGEMENT
3. RESPONSIBILITY FOR SYSTEM SERVICING
4. RESPONSIBILITY FOR SYSTEM/PAYLOAD INTEGRATION

TECHNICAL

1. CROSSTALK (ANTENNA SPILLOVER/SIDE LOBES)
2. LINE-OF-SIGHT BLOCKAGE (ANTENNA TO ANTENNA)
3. TRANSPORT TO SYNCHRONOUS ORBIT (TRANSPORT SYSTEM)
4. RELIABILITY (REQUIREMENT VARIATION)
5. OBSOLESCENCE (EQUIPMENT REPLACEMENT)
6. STABILIZATION (TOTAL PLATFORM)
7. POINTING (GIMBALED SYSTEM/BEAM CONTROL)

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CONCLUSIONS

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During the study summarized in this document, a brief analysis has been made to identify the emerging telecommunication needs and the likely requirements which these needs may place upon geosynchronous Information Services Platforms between the present time and the year 2000. From these requirements, a limited number of representative models for future telecommunications systems were hypothesized in order to provide a basis for suggesting likely system development requirements and technological improvements or breakthroughs needed to meet the forecasted needs. Six system models or categories of application evolved during the study. From these system models, common system design requirements were identified which in turn provide a basis for identifying promising areas for support when planning and allocating funds for research and development projects. Thus, while this effort has only been a preliminary investigation of the problem, it perhaps can be expanded in future studies to create a model for program planning purposes that provides continuing traceability from R and D projects to system design requirements to user needs.

Some of the principal conclusions reached during the study are summarized on the facing page. Additional supporting research and technology requirements which should be noted include:

- Development of antennas with high equivalent isotropically radiated power but with low total power output for closer beam spacing.
- Development of stability and control systems to reduce pointing errors to 0.05 of beamwidth (e.g., 0.0075 deg).
- Continued R&D leading to eventual use of 30, 60 and 90 GHz bands.
- Continued development of optical technology for space relay applications.
- Development of techniques for construction/assembly and precision alignment of large space structures with compound surfaces.

CONCLUSIONS

PROJECTED GROWTH FOR INFORMATION SERVICES (DOMESTIC AND INTERNATIONAL) WILL EXCEED SYSTEM CAPABILITY CURRENTLY PLANNED FOR YEAR 2000

EXPANSION OF GEOSYNCHRONOUS INFORMATION SERVICE PLATFORMS IS REQUIRED

FUTURE SYSTEM CAPABILITY DEPENDS UPON MULTIPLE FACTORS INCLUDING REGULATORY POLICIES, NEW ELECTRONIC TECHNOLOGY AND DEVELOPMENT OF TECHNIQUES FOR PRECISION ASSEMBLY OF LARGE ANTENNA STRUCTURES IN SPACE

LARGE MULTIFUNCTION INFORMATION SERVICE SATELLITES WILL PROBABLY BE DESIGNED TO INITIALLY OPERATE IN THREE BANDS

- HEAVY ROUTE TRAFFIC - 28/19 GHz
- BROADCASTING, DATA COMMUNICATIONS AND INTERACTIVE SERVICES - 14/12 GHz
- NETWORKING - 6/4 GHz

PRESENT R&D EXPENDITURES OF TELECOMMUNICATIONS INDUSTRY APPEAR ADEQUATE TO SUPPORT COMMUNICATION/COMPUTATION SUBSYSTEMS TECHNOLOGY GROWTH REQUIRED FOR SYSTEMS OF YEAR 2000

DEVELOPMENT RISKS ASSOCIATED WITH SPACE CONSTRUCTION OF LARGE-SCALE ADVANCED INFORMATION TRANSFER SYSTEM CONCEPTS NEED TO BE REDUCED IN ORDER TO ATTRACT VENTURE CAPITAL

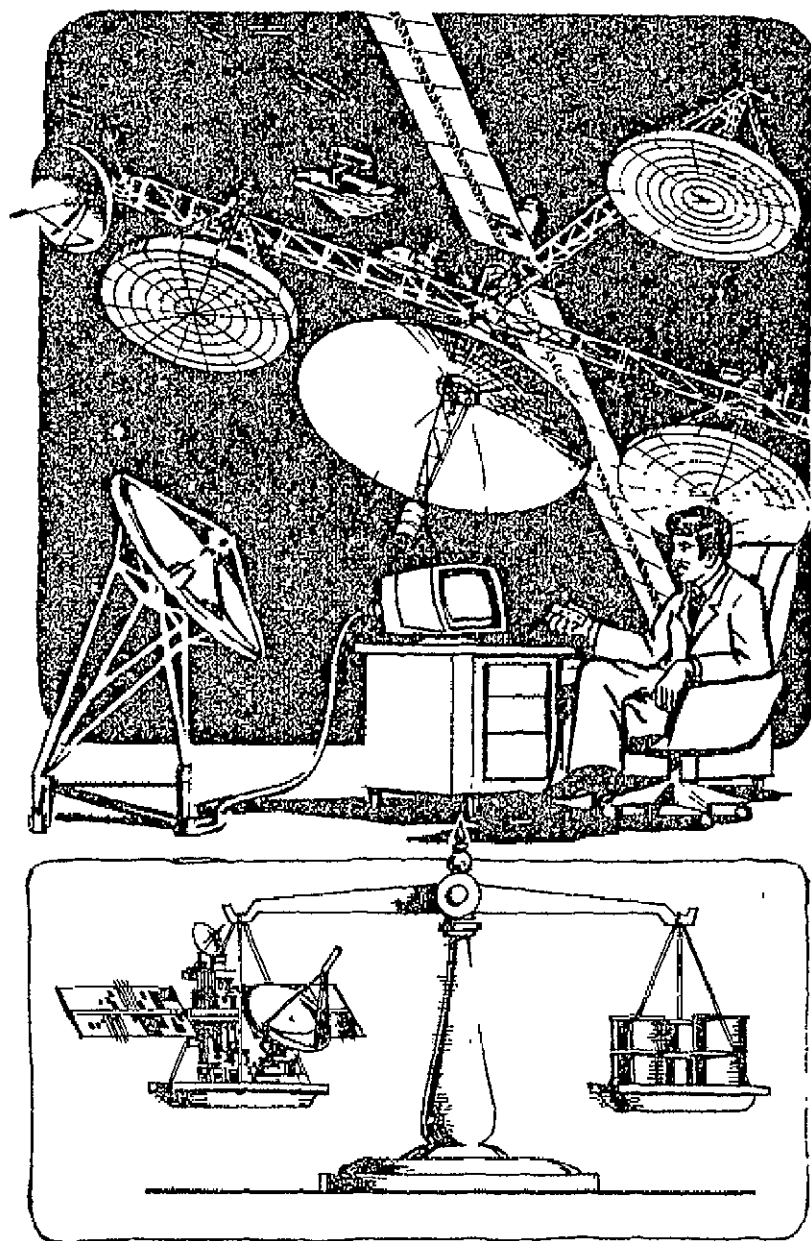
On the basis of the work done to date, two basic recommendations are offered. The first is that this nation should support the expansion of communication services on a global basis by encouraging the concept of "complexity inversion," i.e., placing the larger more sophisticated equipment in space and making the simpler, lower cost items available directly to the users on the ground. This concept results in a low per unit cost for Earth stations and thus in turn will stimulate the market for new services and new customers.

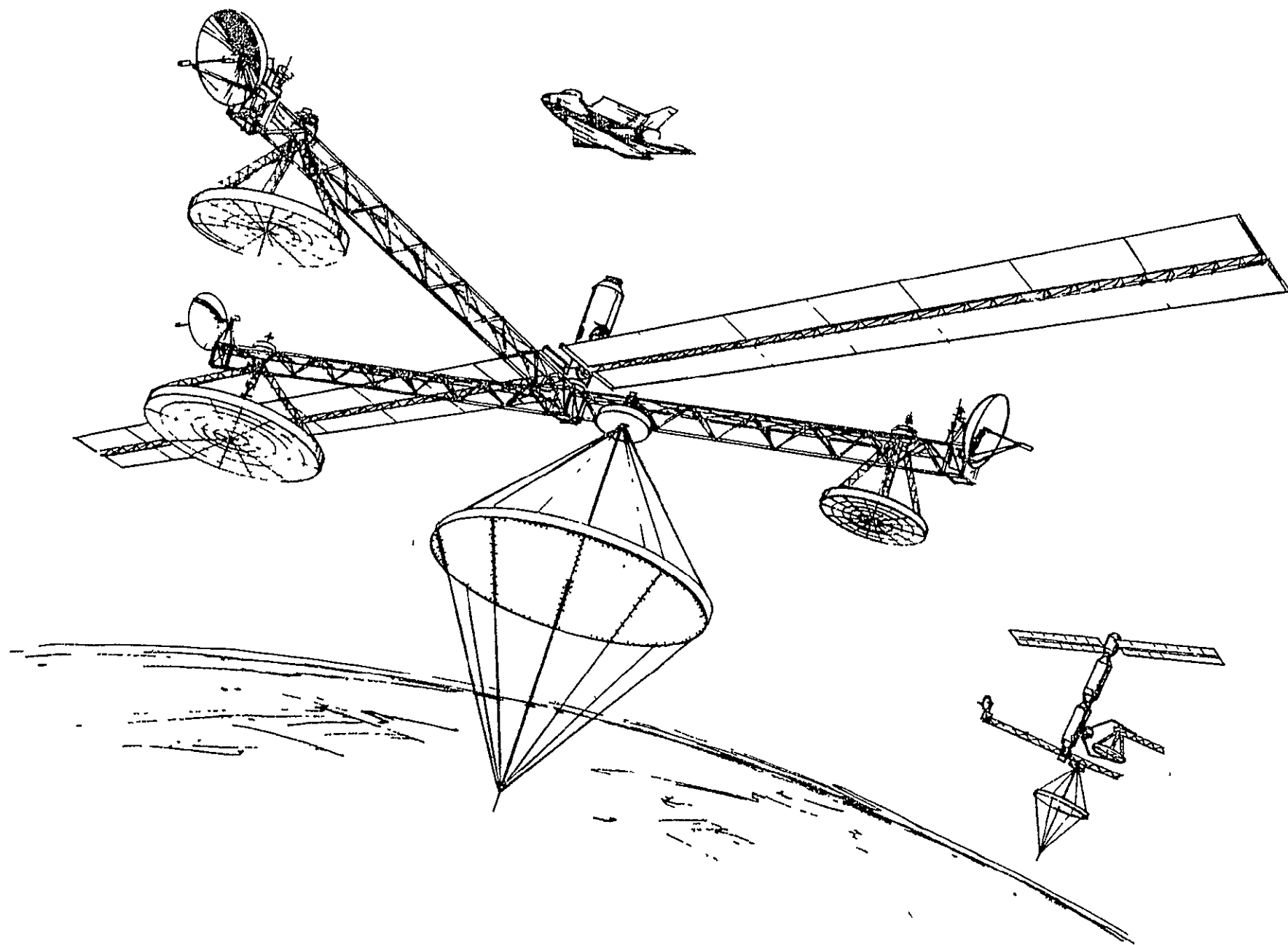
Secondly, implementation of the concept of "complexity inversion" requires this nation to encourage, by whatever means possible, the development of the technology and capability to construct platforms in space and to service geosynchronous Information Service Platforms.

The benefit to the United States in supporting these recommendations is that it keeps this nation ahead of competitors in high technology areas and it provides exportable products and services favorable to a positive long-term balance of trade.

GEOSYNCHRONOUS INFORMATION SERVICE PLATFORMS

- EXPAND SERVICES ON A GLOBAL BASIS
- LOWER EARTH STATION COSTS BY COMPLEXITY INVERSION
- DEVELOP TECHNOLOGY TO BUILD AND OPERATE INFORMATION SERVICE PLATFORMS
- BENEFITS TO THE UNITED STATES:
 - KEEP AHEAD OF FOREIGN COMPETITION
 - EXPORT PRODUCTS AND SERVICES FAVORABLE TO BALANCE OF TRADE
- KEY ADVANCE TECHNOLOGY AREAS
 - MICROWAVE COMPONENTS
 - LARGE PRECISION ANTENNAS
 - HIGH-POWER CAPABILITY
 - SPACE CONSTRUCTION MATERIALS AND METHODS
 - MANNED OPERATIONS AT GEOSYNCHRONOUS ORBIT





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